

SMART OFF-GRID SOLAR APPLIANCES



Using remote monitoring to improve efficiency, performance and affordability

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Efficiency for Access Coalition

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DISCLAIMER

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CONTEXT

This report explores how remote monitoring technologies are transforming the off-grid solar appliance sector, with a focus on improving efficiency, performance, and affordability. It draws on insights from companies supported through the Efficiency for Access Research and Development Fund, including those funded under the recent Agritech Call, which focused on enhancing productivity and sustainability in agriculture. The report integrates learnings from other grantees from earlier calls, such as the Cooling Call and the First Open Call, alongside insights from the broader sector.

The report identifies key opportunities and challenges in deploying remote monitoring across diverse contexts, from agriculture and healthcare to fisheries and retail. It outlines how companies are integrating monitoring into their operations, the role of open-source and proprietary tools, and how data is being used to support predictive maintenance, financing models, and the implementation of carbon credits.

Efficiency for Access is a global coalition dedicated to advancing access to energy and affordable, energy efficient appliances in underserved communities. It is a catalyst for change, accelerating access to off- and weak-grid appliances to boost incomes, avoid carbon emissions, improve quality of life, and support sustainable development. The coalition is co-chaired by UK aid from the UK government via the Transforming Energy Access platform and the IKEA Foundation. Efficiency for Access is jointly managed by Energy Saving Trust and CLASP.

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GLOSSARY

KEY TERMS	DEFINITION
Bluetooth	A wireless technology for exchanging data over short distances using radio waves, which can be used to connect an appliance to the owner or an agent's phone.
Cloud-based	Technology that uses remote servers hosted on the internet to store and manage data instead of local servers or computers
Digital Monitoring, Reporting, and Verification (dMRV)	Systems that use digital tools to track and report emissions reductions in carbon projects
Global Positioning System (GPS)	A satellite-based navigation system used for geolocation tracking
Global System for Mobile Communications (GSM)	A standard to ensure mobile phones and devices can communicate over cellular networks.
Internet of Things (IoT)	A network of physical devices with sensors, software, and other technologies to connect and exchange data.
Low-Power Wide-Area Network (LPWAN)	A type of wireless telecommunication network designed for sending small data packages over long-range communications.
Pay-As-You-Go (PAYGo)	A financing model allowing customers to pay for appliances in instalments. When payments are missed the appliance may be remotely disabled/ locked.
Results-Based Financing (RBF)	A funding approach that disburses payments based on the achievement of predefined results or performance targets.
Radio-Frequency Identification (RFID)	A technology using electromagnetic fields to exchange small amounts of data at close range, such as from an appliance to the owner or an agent's phone.
Smart	Devices or systems with embedded technology enabling data collection, automation, and connectivity.



Remote monitoring in action as a worker stands beneath a solar panel.
Photo credit: Simusolar

INTRODUCTION

Imagine you are a farmer and could get an automated text to let you know your solar water pump is blocked, or you're a fish distributor and can track the temperature of your cool boxes — so you notice one has been left out in the sun? These are some of the emerging real-life applications of remote monitoring for off grid appliances across sub-Saharan Africa and Asia....

Remote monitoring has emerged as a transformative tool in the off-grid solar appliance sector. Initially developed for mini-grids and solar home systems, these technologies are now being adapted to manage and optimise stand-alone appliances such as refrigerators, water pumps, mills, and cooking devices. As hardware becomes more affordable and digital infrastructure improves, remote monitoring is opening new avenues for business innovation, customer service, and data-driven impact assessment. Yet adoption remains fragmented. While some appliance companies are embedding monitoring into their core offerings, others are still navigating how to design, implement, and pay for these systems. Without strategic direction, there is a risk that remote

monitoring becomes a technical add-on rather than a lever for market transformation. This report aims to fill that gap by answering three questions:

- 1. Where are we now?** What's the current state of remote monitoring technology in the appliance sector?
- 2. Where do we need to go?** What roles can it play in scaling access, improving reliability, and unlocking finance?
- 3. How do we get there?** What are the priority actions for companies, funders, and public sector enablers?

Drawing on interviews, case studies, and learnings from the Efficiency for Access Research and Development Fund, we provide a practical guide for companies and stakeholders looking to realise the full value of remote monitoring - not just as a tool for performance tracking, but also as a driver of inclusive, affordable, and sustainable appliance markets.

KEY TAKEAWAYS



REMOTE MONITORING IS A BUSINESS ENABLER, NOT JUST A TECHNICAL TOOL

Business models like Pay-As-You-Go and Energy-as-a-Service use remote monitoring alongside customer relationship management tools to track appliance use, manage payments, and enforce service contracts. This can unlock access to appliances for lower-income users and create new revenue opportunities for companies and investors. Monitoring data can enable access to carbon credits and provide evidence for results-based financing and investments, which can further increase affordability.



BETTER DATA = BETTER SERVICES

Data allows companies and other organisations to understand real-world appliance performance and usage, segment customers, and tailor services or upgrade offers. Data can be used to improve design, reduce costs and personalise customer support.



SMART APPLIANCES CAN IMPROVE EFFICIENCY, PRODUCTIVITY AND TRUST

Monitoring technologies enable applications like automated irrigation, cold chain tracking, and remote farm or clinic management. For example, solar-powered appliance manufacturer, Synnefa's smart farming solutions have demonstrated 50% reduction in water use and 40% reduction in fertiliser rates alongside 30% increases in production⁽¹⁾.



PREDICTIVE MAINTENANCE PROVIDE BENEFITS FOR END-USERS AND DISTRIBUTORS

Enabling predictive maintenance and real-time diagnostics can help reduce appliance downtime, extend product life, and lower service costs. Early insights from Innovex's REMOT technology show a 10% reduction in the need for maintenance visits, reduced appliance downtime, and cost savings related to replacing parts.



AFFORDABILITY AND ADAPTABILITY REMAIN BARRIERS

Existing solutions can be too expensive or complex for smaller companies. Providers should develop services tailored to different requirements, such as modular tools and solutions that work in low-connectivity areas. Open-source tools are an important offering, allowing a low-cost entry point for companies to explore how they can integrate remote monitoring, as well as avoiding duplicated efforts.

KEY TAKEAWAYS



INTEROPERABILITY IS IMPORTANT FOR EFFICIENCY AND INNOVATION

A lack of interoperability across hardware and software limits remote monitoring's full potential. Without shared standards, companies face high integration costs, limited choice of technology partners, and challenges scaling across different appliance types or geographies. Industry-wide efforts, like GOGLA's Connect Initiative, are helping define open, secure protocols to enable compatibility. Promoting interoperability can reduce costs, improve service delivery, and accelerate innovation across the sector.



COORDINATED ACTION IS NEEDED TO SHAPE THE FUTURE

Companies, service providers, funders, and policymakers all have roles to play. Established companies can deepen R&D and share learning; new entrants need practical guidance; and associations like GOGLA can enable open, collaborative infrastructure. Funders should catalyse innovation paths, and policymakers can prepare enabling environments through inclusion, data protection, and eventual regulatory alignment.



Processing mangoes inside a remotely monitored solar dryer

Photo credit: Synnefa



Two workers preparing a solar-powered water pump for work.
Photo credit: Simusolar

1. WHY IS REMOTE MONITORING IMPORTANT FOR SOLAR-POWERED APPLIANCES?

Solar-powered appliances are essential tools in addressing some of the most pressing global development challenges -from energy poverty and food insecurity to climate vulnerability. Despite the proven impact of solar appliances, existing sales meet less than 2% of the total need⁽²⁾. Remote monitoring can help to bridge this gap.

By enabling real-time tracking of appliance performance, energy usage, and faults, it opens opportunities to better understand end-user behaviour, implement innovative business models and enhance service delivery. For end-users it can introduce new ways to pay for appliances, reduce downtime due to improved repair and maintenance and offer new services, such as automating processes. This technology is becoming increasingly accessible due to falling costs of technology⁽³⁾, improvements in software, and the expansion of mobile network coverage⁽⁴⁾.

The data collected from sensors is transmitted through communication networks, which are becoming increasingly reliable and affordable even in remote regions. This ability to link solar appliances to systems and platforms — the 'Internet of Things' (IoT)— unlocks a range of opportunities for companies, end-users and the wider sector.

Smart Pay-As-You-Go (PAYGo) technology can allow for payment-linked appliance access — enabling distributors to lock devices when payments aren't made. This has been crucial in the solar home system market⁽⁵⁾ and is becoming more common in appliances such as cookstoves, solar water pumps and refrigerators⁽⁶⁾. Between 2018-2023, 55% of household and small business appliances and 43% of productive use of energy appliances were sold on

PAYGo⁽⁷⁾. Remote monitoring is especially relevant in business models where the company retains ownership of the appliance, allowing for more effective risk management and service delivery.

Although PAYGo is the most established use of remote monitoring, it has potential to be used for a wide range of applications, such as:

- Access to finance
- Delivering user services
- Monitoring performance
- Repair and maintenance
- Generating insights

With the falling cost of sensors and improvements in power consumption and data requirements, integrating remote monitoring into solar appliances is becoming more feasible across different sectors.

"Remote monitoring can deliver tangible benefits, (including) faster repairs and fewer breakdowns."

The integration of artificial intelligence (AI) provides an opportunity to enhance remote monitoring systems through predictive analytics, automated decision-making, and enhanced operational efficiency⁽¹¹⁾.

For example, AI can detect patterns in sensor data, predict maintenance needs, and optimise appliance performance without requiring constant human intervention. This can reduce maintenance costs and increase system uptime, particularly for businesses operating in hard-to-reach areas. These tools can also be used to understand and predict customer behaviour, such as usage and payment patterns.

Remote monitoring systems enable innovative consumer financing models⁽¹²⁾, allowing customers to access technologies through payment plans and helping companies provide Energy-as-a-Service. Instead of making an upfront purchase, customers can pay incrementally over time or based on their usage when combined with operational sensors.

Remote monitoring systems can track carbon emissions reductions, enabling companies to monetise their environmental impact through carbon credits⁽¹³⁾. This provides an additional revenue stream; particularly where renewable energy sources replace fossil fuels.



An Innovex motherboard helps to operate a remote monitoring device



Amped engineer showing a customer a refrigerator
Photo credit: Amped Innovation

2. HOW DOES THE TECHNOLOGY WORK?

Remote monitoring technology works by collecting, transmitting and analysing data from appliances. This process is enabled by integrating various sensors, data communication systems and software platforms.

The core components of remote monitoring systems can be categorised into the following key areas^(14,15):

1. Power consumption sensors

These sensors monitor the energy consumption of an appliance, capturing data on how much power is being used over time. They can provide insights into operational efficiency by identifying consumption patterns. This can be used to optimise appliance performance and can signal faults or inefficiencies.

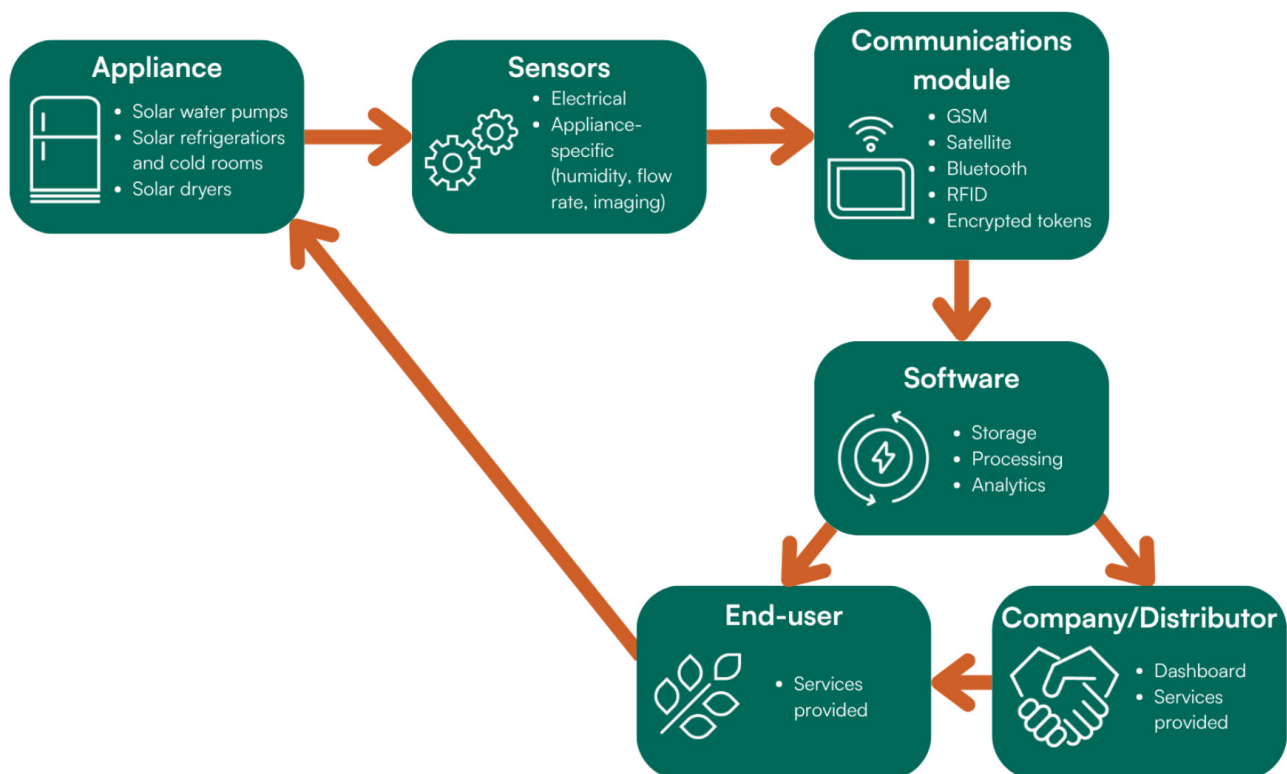
2. Operational sensors

These sensors can collect data on service delivery and monitor the status of components for repair and maintenance.

Service delivery monitoring involves tracking parameters such as temperature, pressure, speed and flow rates, depending on the appliance. For example, temperature, humidity and door-opening sensors can be used in cold storage units or flow rate sensors in solar water pumps. This data can also be used for predictive repair and maintenance, alongside sensors which can measure vibrations, noise or component stress.

Companies need to select sensors which align with monitoring needs, taking into consideration sensor sensitivity, calibration requirements, measurement range and sampling rate. Off-the-shelf monitors are available for measuring parameters in solar water pumps and refrigerators. However, areas where there is a need for technological development include measuring flow rate for milling machines and measuring how much produce is in a cold room (which could be done by weight or by using cameras and AI to identify produce).

How remote monitoring works



3. Communication equipment and systems

Once data has been collected by sensors, it needs to be transmitted to a central monitoring platform. Cellular Global System for Mobile Communications (GSM) is the main communication network used to transmit data from the remote appliance to a central server or a cloud-based platform. Across its clients, Innovex has identified GSM connectivity issues in around 10% of appliance locations across Sub-Saharan Africa. A lack of connectivity may also affect locations where companies or their agents sell their products. The Global System for Mobile Communications Association (GSMA) has been collaborating with the World Bank to share data on mobile tower locations and signal strength to help inform site selection and deployment. By making this information available to donors and productive-use companies, stakeholders can better understand the feasibility of remote monitoring technologies and different communication protocols⁽¹⁶⁾.

In remote areas, satellite technology can be used if a reliable connection is required, but this is expensive. Low-Power Wide-Area Network (LPWAN), Wi-Fi, Bluetooth and Radio-Frequency Identification (RFID) can be used, but these have limitations around how much data can be transferred and over what distance.

Communication protocols need to be designed based on the availability of networks in the appliance's location, which can be challenging in off-grid areas⁽¹⁷⁾. Companies should assess whether their customers

have reliable access to connectivity. Without this, remote monitoring systems may unintentionally exclude users in low-signal areas. Hybrid or offline-compatible tools can mitigate these risks.

For low-data settings, distributors may consider options such as offline data loggers that agents can read during routine visits, or temporary plug-in monitoring modules. Where continuous data is not critical, customer-reported usage via SMS or voice surveys may also offer useful insights.

"Companies should assess whether their customers have reliable access to connectivity."

One option is to use a monitoring device which produces an encrypted token, which can be sent by text to transmit data. The main limitation of this approach is that it requires the user to perform an action and can only send a small amount of instantaneous data⁽¹³⁾. Bluetooth, Wi-Fi or RFID can be used alongside a user or agent's phone, which can pick up data stored on an appliance and transmit it when the phone is in an area with signal.

There may be communication channels back to the appliance owner, such as notifications around payment or maintenance. These may be delivered through an online platform or database, through text messages or email alerts.

COMMUNICATION SYSTEM ⁽¹⁾	COST PER CONNECTION (USD PER MONTH)	RANGE AND CONNECTIVITY	DATA CAPACITY ⁽¹²⁾
Cellular GSM	\$1 — 10	High: 83% of the population of Sub-Saharan Africa is covered ⁽¹⁸⁾	High: Suitable for sending regular performance updates (40 kbps — 100 Mbps)
Satellite	\$10 — 50	Very high: Covers very remote villages	Medium: Daily reports or fault reports (64 kbps — 1 Mbps)
LPWAN	\$0.10 — 0.50	High (but low availability in some areas of Africa)	Low: Small readings (1 — 50 kbps)
Wi-Fi	Low	Low: Within a building	High: Needs to be near a central hub (100 — 600 Mbps)
Bluetooth	No ongoing cost ¹	Low: A few metres	High: Suitable for transferring stored data (up to 2 Mbps)
RFID	No ongoing cost ¹	Very low: A few centimetres	Very low: Very simple ID (1kb)
SMS messaging	\$0.10 — 0.50	High: Uses mobile networks	Very low: Short messages (140 bytes per message)

1. Although there is no ongoing cost to transfer data from a device to a mobile phone, there may be data costs to transfer this data to servers. This could be done over a WiFi connection or using mobile data.

Table: Cost, range and data capacity for different communication systems



Two women showcasing the Evosav chiller
Photo Credit: Savanna Circuit

4. Data handling, processing systems and security

After data has been transmitted, it is stored, processed and analysed on cloud-based or local platforms. Data handling systems can organise and manage large volumes of data. The role of artificial intelligence (AI) in this process is becoming increasingly important. These technologies can analyse data to detect patterns, predict potential issues and automate decision making. For example, the Efficiency for Access Research and Development Fund has funded Innovex to explore AI for predictive repair and maintenance (see case study 3).

"Physically, appliances deployed in off-grid environments can be vulnerable to theft or tampering."

Companies also need to think about both physical and digital security. On the digital side, companies need to implement measures to protect data and systems from unauthorised access, manipulation or loss. This includes encryption, authentication protocols and adherence to data privacy standards. Physically, appliances deployed in off-grid environments often contain valuable components such as batteries, which can be vulnerable to theft or tampering. Enclosures, tamper alerts, GPS-technology and secure device design can help to mitigate these risks.

5. Powering remote monitoring systems

Most appliances with remote monitoring systems can power these components through their own power supply. However, for devices such as cool boxes, a separate power supply is needed, such as a rechargeable battery.



Simusolar pump inverter

If appliances are used in cloudy or shady areas, then a back-up power supply may be needed to allow continuous data collection and transfer. Smart plugs are available which plug in between the socket and the appliance. These can be used for piloting or research projects but can encounter issues if the appliance is unplugged and separated from the smart plug.

2.1. How to integrate remote monitoring into appliances?

There are several options for companies who want to integrate remote monitoring into appliances. Section 2.3 provides a short guide to key questions to consider, and signposts where this information can be found in this report.

Remote monitoring can be as simple as tracking energy use, or as complex as enabling PAYGo functionality, predictive maintenance, carbon tracking, or integration with AI systems. The design of a monitoring system should therefore be closely aligned with a companies' business model, user base and intended applications.

A key decision to be made is whether to use open-source tools, develop tools in-house, or to purchase proprietary software. The decision will depend on what applications remote monitoring is used for, budget and available expertise.



Engineers at Innovex build circuit boards for operation in devices used for remote monitoring

Photo credit: Innovex

2.1.1. Open-source tools

Open-source platforms offer companies a low-cost, adaptable foundation for developing remote monitoring capabilities⁽¹⁹⁾. These tools are especially attractive for early-stage companies and organisations looking to avoid being locked-in to a platform.

Open-source tools⁽²⁰⁾ offer an affordable and adaptable solution for businesses implementing remote monitoring. These platforms allow companies to adopt proven technologies quickly, reducing development time and costs. Open-source systems encourage collaboration across the public and private sector, helping to standardise solutions and drive innovation⁽²¹⁾.

Advantages include:

- Lower or no upfront costs.
- Flexibility.
- Better interoperability, and benefiting from community-driven innovation and learnings.
- For public entities, it ensures vendors' independence in the long run — spending public money on public goods.

Considerations:

- In some cases, it may require internal technical capacity to customise and maintain systems, and to ensure cybersecurity and data integrity.

"Open-source tools offer an affordable and adaptable solution for businesses implementing remote monitoring."

Examples

Several of the companies we spoke to described how they used open-source tools during their development stages.

Open-source approaches are particularly useful when a company has skilled developers or wants to maintain full control over its data architecture and customer experience. Companies may struggle with ongoing maintenance and customisation of tools without dedicated support. Companies may have concerns about data privacy when using open-source tools. However, whilst the tools are freely available, companies would still own their data, and this wouldn't be accessible to others if they take steps to protect the data.

NAME	APPLICATION	DEVELOPER
Cicada Modules	The WiFi Cicada offers a way for energy providers to pair with satellite technology to provide internet access to remote communities, both for the purposes of IoT device communication and for general community access to WiFi.	OKRA
Open Smart Meter	Original equipment manufacturer-agnostic, PAYGo-enabled GSM electricity meter	First Electric
Open PAYGo Pass	Radio frequency identification (RFID) based badge system to activate PAYgo functionality	Solaris Offgrid (now Masunga)
Open PAYGo Token	Open-source token system to enable PAYGo functionality in new products	Solaris Offgrid (now Masunga)
MicroPowerManager	Decentralised utility management	Inensus
Airlink	Connect PAYGo IoT devices to compatible servers via Bluetooth gateways	Simusolar
Battery Management System	Open-source battery management system with communication interfaces	LibreSolar

Table: Examples of open-source tools to monitor appliances remotely

2.1.2. In-house development

Some companies choose to develop their own remote monitoring platforms from the ground up — either to differentiate their services, maintain tighter control over data, or respond to highly specific operational requirements.

Advantages include:

- Maximum customisation.
- Full data ownership.
- The ability to iterate quickly based on user feedback.

Considerations:

- Requires significant investment in software development, long-term maintenance and possibly dedicated hardware integration.

This approach is best suited for companies with sufficient internal expertise, long-term funding, or products requiring highly specialised features not available in existing platforms.



Examples

- Ecozen has developed hardware and software for its refrigerators, freezers and cold-rooms⁽²²⁾ in-house.
- Synnefa has used open-source tools alongside in-house expertise to develop their approach to remote monitoring 'FarmShield'. FarmShield has been designed with interoperability as a key feature, so it can integrate with off-the shelf sensors and field equipment through universal connectors and adaptable in-put configurations. This means farmers aren't locked into one supplier — which can lower hardware costs and makes it easier to repair or upgrade equipment.

2.1.3 Proprietary services

For many appliance manufacturers or distributors, licensing proprietary remote monitoring platforms offers a fast and reliable way to deploy robust systems with minimal internal development.

Advantages:

- Speed of deployment.
- Customer support.
- Integration with financing platforms.
- Proven reliability.

Considerations:

- Higher costs over time.
- Less flexibility in customisation.
- Risk of vendor lock-in.
- Potential data-sharing limitations.

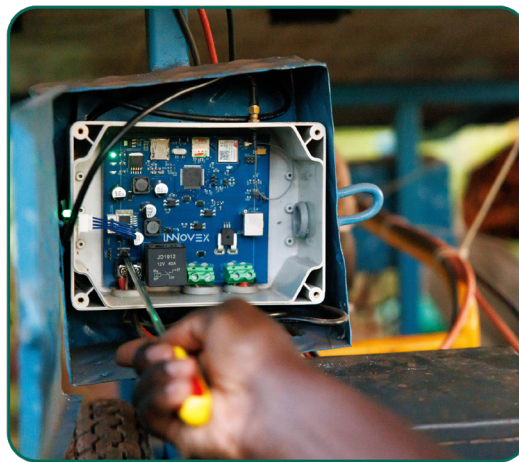
Examples

- Innovex offers end-to-end remote monitoring solutions, including both hardware and software, with capabilities spanning device tracking, diagnostics, and PAYGo⁽²³⁾.
- Angaza provides PAYGo integration, alongside additional services for customer engagement, and analytics, with a track record across multiple solar appliance types⁽²⁴⁾.
- Koolboks is partnering with Innovex and Inclusive Energy to pilot integration of advanced remote monitoring technology into their cooling products.
- Proprietary tools are well-suited to companies focused on rapid market entry, or those seeking to outsource technical complexity while ensuring strong functionality.

2.2. How companies cover the costs of remote monitoring

Implementing remote monitoring systems involves various costs, including hardware, software platforms, data transmission, and ongoing maintenance. The financial approach to these costs varies across providers and is influenced by factors such as the type of appliance and the chosen business model.

Remote monitoring costs can be integrated into the appliance's initial cost or structured as part of a subscription service. For example, monitoring support might be included for the first one or two years post-purchase, or aligned with the duration of a PAYGo lease. Innovative business models, such as Energy-as-a-Service can absorb remote monitoring costs. In these models, customers pay for the use of an appliance, rather than the equipment itself, allowing providers to include monitoring expenses in their overall service fee. While these models can absorb monitoring costs, they are often costly to operate and may require end-user subsidies to be viable. Early insights from pilots suggest the importance of subsidy design to support long-term sustainability.



An Innovex REMOT device in a solar water pump

In projects requiring results-based financing (RBF) or detailed reporting, remote monitoring can be a more cost-effective alternative to in-person visits for verification and compliance. Costs can be incorporated into the overall project budget, supporting accurate data collection and reporting. However, while remote monitoring offers efficiency, it has challenges due to perceived or actual vulnerabilities to fraud and data manipulation.

It's important to note that cost-effectiveness alone is not sufficient for effective monitoring and evaluation — data integrity, accountability, and reliability are equally critical.

Example cost structures

Embedded in product purchase price

Some providers incorporate the full cost of remote monitoring into the retail price of the appliance. Ecozen follows this approach by embedding monitoring into its cold storage products. While this can increase the initial price, it allows the company to leverage monitoring data for product improvement, user insights, and reporting for funders. This enhances long-term value for both the business and the customer.

For higher value appliances, such as cold rooms, remote monitoring can be a smaller percentage of the total product cost. Solar Cooling Engineering estimates that monitoring adds three — four percent to the cost of a cold room. The company's current solution costs EUR 1,500, with previous open-source systems costing as low as EUR 500 (though it had reliability issues). Customers are then responsible for monthly operating costs: EUR 5 for cloud access and EUR 5 for data.

Bundled or subscription-based services

Some companies offer remote monitoring as part of a bundled package that includes hardware, software, and ongoing support. For example, Synnefa provides farmers with an automated irrigation system bundled with monitoring tools. Customers can either pay a subscription from USD 400 per year or make a one-time upfront payment from USD 1,200 for the full system, which includes solar panels, batteries, and access to their Farm Cloud platform. This approach spreads costs over time and supports affordability for smallholder farmers.

"Some companies offer remote monitoring as part of a bundled package that includes hardware, software, and ongoing support."

Service-based models

For companies using service-based models, remote monitoring costs are integrated into recurring service fees rather than capital expenditures. Rural Aquaculture Development (RAD) is piloting mobile cool boxes with monitoring for performance and efficiency. RAD used a platform costing ~USD 100 per device per month during a pilot, which it found unsustainable. RAD is exploring more affordable options and plans to cover monitoring costs through a Cooling-as-a-Service model, which would embed costs into customer payments over time.

Carbon credits and other financing

SunCulture use remote-monitoring data from solar irrigation pumps to quantify carbon savings and monetise these credits, subsidising upfront costs.

In the cookstove sector, suppliers leverage simple sensor-enabled monitoring to validate carbon credits using revenues to offset distribution and monitoring investments.

Hardware sale with tiered service costs

Remote monitoring hardware is sold as a one-off component, with ongoing service fees depending on the level of functionality or support. Innovex charges around USD 40—80 per monitoring device.

"For higher value appliances, such as cold rooms, remote monitoring can be a smaller percentage of the total product cost."

Ongoing costs vary based on service tier and are typically absorbed by manufacturers or distributors. Bulk procurement and integration during manufacturing can reduce unit costs further. This approach offers flexibility for companies scaling across different appliance types or service levels.



Remote monitoring boxes can be maintained manually, such as this one beneath a solar water pump

Photo credit: Simusolar

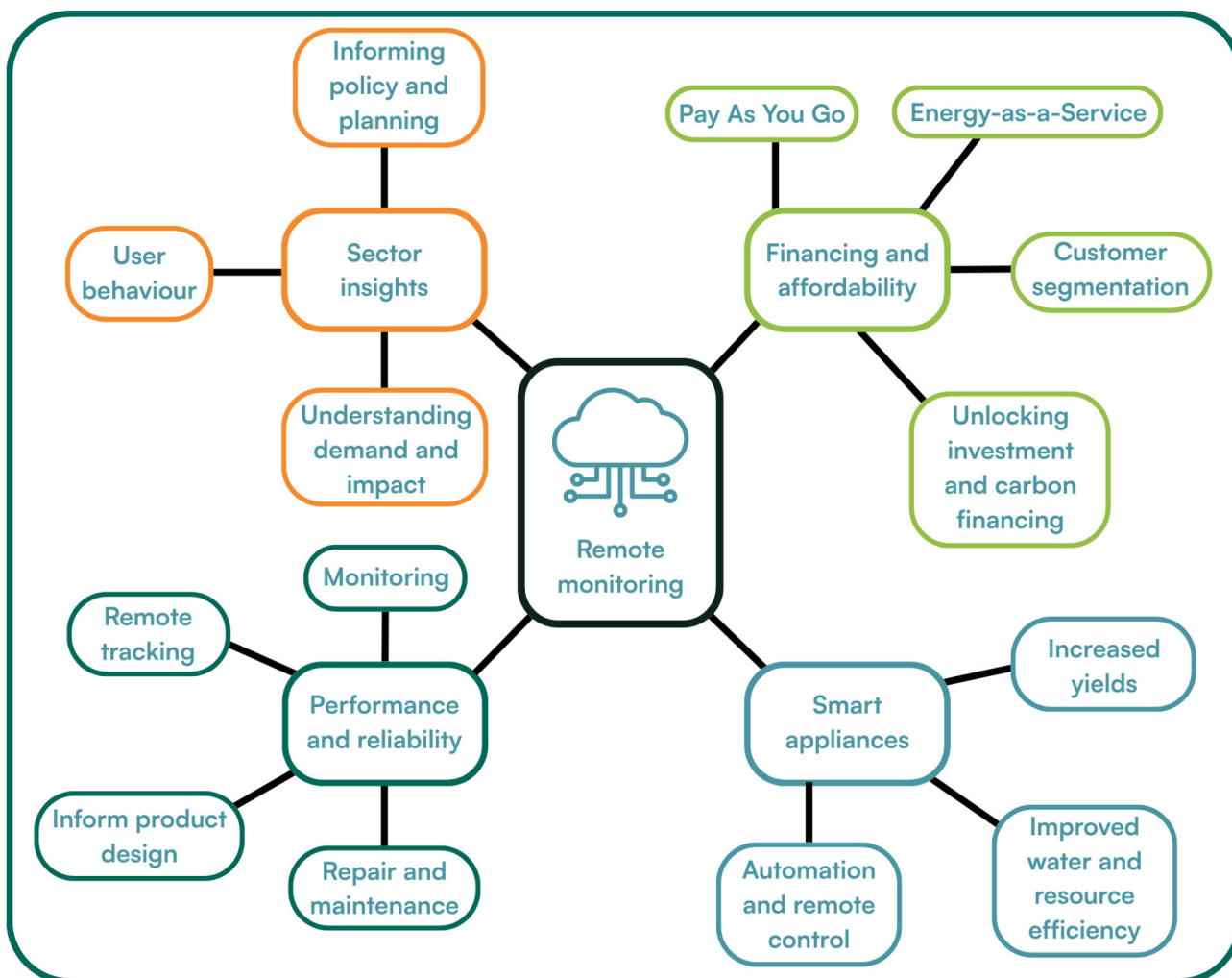
2.3. Guiding questions for companies

QUESTIONS	DETAILS AND OPTIONS
What's your business case for integrating remote monitoring?	• Improve after-sales service and maintenance • Enable PAYGo models • Monitor product performance and usage • Generate data for impact reporting • Access carbon credits
What model should be used for integration?	• Open-source • In-house development • Proprietary platforms
What technical specifications are important?	• Communications: remoteness and data capacity needs, end-users • Live or delayed data transmission • Robustness: weatherproofing, durability, tamper resistance • Applications: what sensors, software and analytics are needed to enable these • Data resolution & sampling rates for different monitoring needs • Power type: compatibility with AC/DC, single/three-phase systems • Security: digital and physical • Is the remote monitoring device integrated into the device, or added on
How should you cover the costs of remote monitoring?	• Through added value for company • Carbon credits by proving usage/emissions reduction • Customer or distributor payment models • Integrated pricing via upfront fees or subscriptions



A farmer watering a field
Photo credit: Aqysta

3. APPLICATIONS OF REMOTE MONITORING



This section explores how remote monitoring is being applied across the sector, drawing on case studies from companies who are pioneering new approaches and demonstrating their potential. For companies new to the sector, this section explains the wide range of ways they can use remote monitoring. Many recent innovations have emerged in agriculture and productive use; remote monitoring is also well-established in solar home systems and emerging in clean cooking. The diversity of use cases continues to expand. We highlight areas of recent innovation, beneficial for all companies in the sector.

3.1. Financing and affordability

One of the most significant applications of remote monitoring is enabling inclusive financing^(25,26). The upfront cost of appliances remains a critical barrier to access. To address this, companies have developed a range of customer financing models, such as PAYGo, lease-to-own, and Energy-as-a-Service, that allow customers to pay in instalments or access appliances without owning them outright. These models require mechanisms to track usage, enforce agreements, and assess repayment risk, which can all be addressed using remote monitoring. When GPS components are included, distributors are also able to track the location of devices.

Section 4 explores some of the challenges around these approaches, particularly considering use of data, customer awareness and remote switch-off.

"Companies have developed a range of customer financing models... that allow customers to pay in instalments or access appliances without owning them outright."

By providing real-time insights into how and when appliances are used, remote monitoring also allows companies to tailor services to customer needs, segment markets, and reduce the likelihood of payment defaults. These capabilities have potential to unlock external investment and enable partnerships with financiers who require verifiable data to assess risk and return.

3.1.1. Pay-As-You-Go

PAYGo business models address the challenge of upfront costs by allowing customers to pay for solar products in manageable instalments.

Remote monitoring supports the management of these payment systems, ensuring continuous service delivery and improving customer satisfaction. For example, Devidayal⁽²⁷⁾ and Koolboks⁽²⁸⁾ have integrated PAYGo into solar refrigerators, offering flexible payment plans that make these appliances more accessible⁽²⁹⁾.

3.1.2. Energy-as-a-Service

Energy-as-a-Service models provide customers with access to solar energy solutions without the need for significant upfront investment. These models are different to PAYGo models as customers pay a fee for a service, such as cooling or irrigation⁽³⁰⁾ rather than financing ownership of an appliance. Remote monitoring and control can enable different customers to unlock appliances and pay for their usage. Examples include Koolboks providing Cooling-as-a-Service to healthcare facilities⁽³¹⁾, and Ennos⁽³²⁾ and Aptech⁽³³⁾ providing Irrigation-as-a-Service.

3.1.3. Customer segmentation

Customer targeting is still largely dependent on geography and local knowledge. However, companies are beginning to develop more sophisticated approaches to customer segmentation (see case study 1). By tracking device usage and the stage of repayment plans, companies can learn the best moment to make offers of product upgrades or trade-ins to customers, the price points at which their current customers are likely to be able to purchase products or services, and the types of products that might suit the energy use of homes or businesses. While these uses of data may improve company performance, there are ethical issues around both the use of data and the potential for AI-driven decisions to be made without human oversight, which could lead to discrimination against certain groups⁽³⁴⁾.

Advances in remote monitoring are creating new opportunities for mini-grid and grid-connected suppliers to improve service delivery and financial sustainability. Using remote monitoring of energy usage and smart load algorithms (non-intrusive load monitoring algorithms), suppliers can identify how electricity is being used within a household or business, such as distinguishing between appliances used for cooking, refrigeration, or other productive uses. This understanding of consumption enables operators to implement differentiated tariffs, such as lower rates for productive use or time-based pricing to encourage off-peak usage⁽³⁵⁾.

3.1.4. Unlocking investment and carbon financing

Remote monitoring plays a role in quantifying the environmental benefits of off-grid energy systems.

A study by Inclusive Energy⁽³⁶⁾ explores the importance of data in biogas carbon projects, illustrating how accurate and real-time data collection can enhance the credibility and value of carbon credits. There are several projects in the cooking sector where costs of devices are reduced by carbon credits, such as burn cook stoves⁽³⁷⁾.

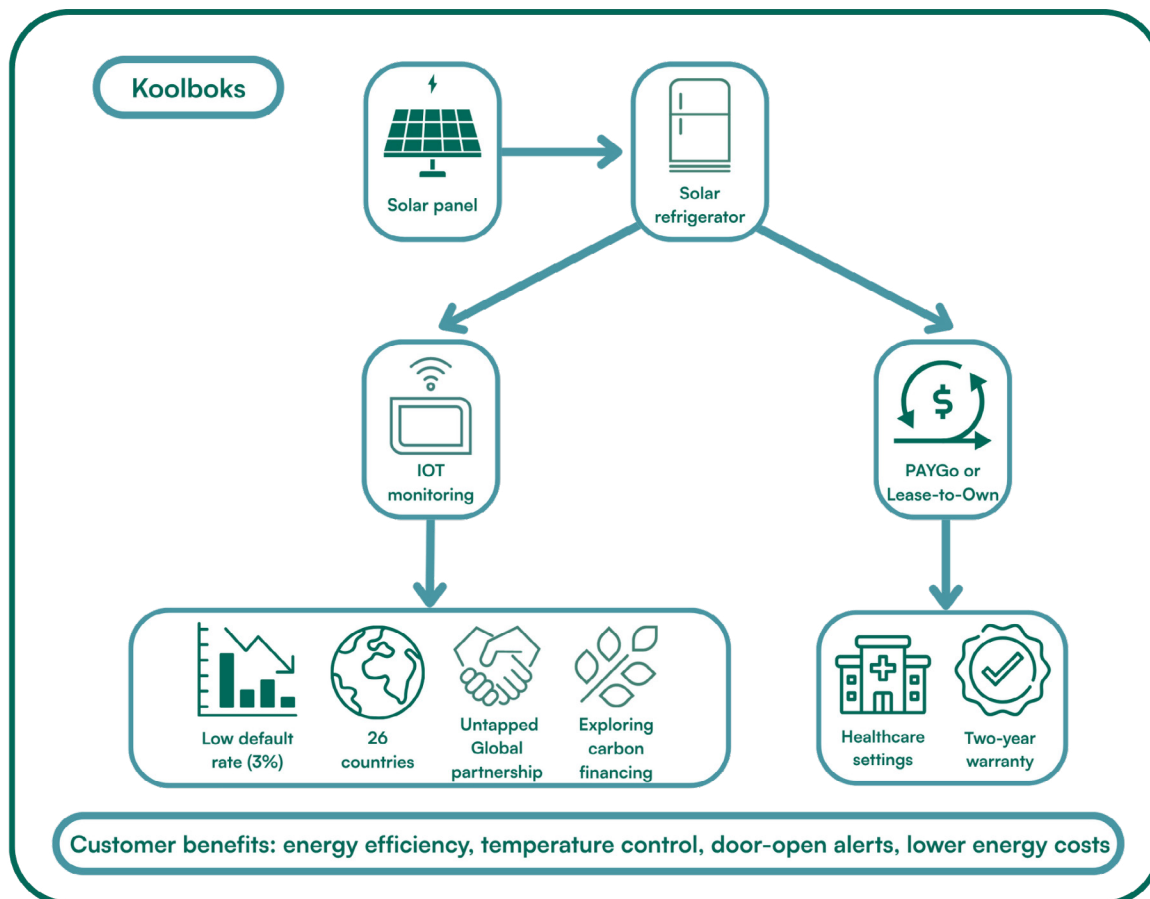
The potential income from solar appliances is less than for cooking but still offers potential to increase affordability. SunCulture uses remote monitoring to track and verify the carbon savings from their solar water pumps, ensuring transparency and accountability in carbon markets⁽³⁸⁾. Ennos recently announced a partnership with Innovex where the company plans to use data from remote monitoring to generate carbon credits⁽³⁹⁾. A lack of clear methodologies for solar appliances means it is currently challenging to calculate the potential income from carbon credits. Values depend on baseline calculations — which will vary based on location.

For example, in a country where the grid has a high renewable energy percentage, the emission reduction potential of solar powered devices may be lower than in a country with a high percentage of fossil fuels. The value of each carbon credit can vary depending on market fluctuations, as well as project additionality — such as improved water efficiency or reduced gender inequalities. There is a need for robust standardised baseline studies and a consolidated solar appliance carbon methodology⁽⁴⁰⁾. The cost and complexity of setting up carbon projects can be prohibitive, particularly for smaller companies.

Aggregation approaches and open data tools may help to lower these barriers, but further innovation is needed to make carbon finance truly accessible across the sector. Carbon finance methodologies have historically relied on manual reporting or inflexible assumptions, limiting their application in dynamic off-grid markets. A recent report by Efficiency for Access⁽⁴⁰⁾ highlighted the importance of enabling digital monitoring and verification (dMRV), through the establishment of an incubation hub. This hub would focus on research and development of dMRV tools for off-grid appliances, as well as developing open-source tools and models to allow developers to adopt and customise them for their own needs.

A recently published guide from GSMA provides further information from companies, including advice on project eligibility, how to evaluate financial viability and on defining strategy⁽⁴¹⁾. Remote monitoring can also be a tool for unlocking results-based finance (RBF) mechanisms or investments, as demonstrated in case study 1. Funders seeking to support productive use or healthcare electrification increasingly require usage data to demonstrate impact (see case study 5).

Case study 1 - Koolboks: improving the affordability of cooling solutions



- **Company type:** Manufacturer and distributor of cooling appliances
- **Technology:** Freezers, refrigerators, and ice makers
- **Location:** Offices in Nigeria, Kenya, Uganda and France, and sells products across 26 countries

Innovative financial approaches

Koolboks' financing approaches allow customers to acquire solar-powered refrigerators through regular instalments, reducing the challenge of large upfront payments. The company provides PAYGo, lease-to-own (particularly in healthcare settings) and Cooling-as-a-Service models. The integration of IoT technology facilitates remote locking of the refrigerators, ensuring timely payments and reducing default rates. This strategy has resulted in a financial portfolio where only around three percent of customers are classified as at risk of non-payment⁽⁴²⁾.

Koolboks has partnered with Untapped Global, a firm that finances tech-enabled companies by leveraging IoT tracking on income-generating assets. Koolboks has secured funding from financial institutions by collateralising receivables, using granular payment data and asset tracking. The company is currently exploring options for carbon financing.

Reducing operational costs

Koolboks offers a two-year warranty on its appliances, covering repairs and replacements, ensuring product reliability and customer satisfaction. Remote monitoring enables proactive fault detection and maintenance, reducing downtime and extending the lifespan of the appliances. This practice provides insights into customer usage patterns, allowing Koolboks to tailor its products and services to better meet customer needs.



Koolboks freezer

Improving customer affordability

To maximise efficiency and affordability for customers, Koolboks' cooling devices are designed to optimise energy use. Features such as temperature control and feedback mechanisms, like alerts when the door is left open, help reduce energy consumption and associated costs.

3.2. Delivering smart services for farmers and appliance users

Remote monitoring can play a role in supporting appliance users, particularly smallholder farmers and micro-enterprises, with services that extend beyond the appliance itself⁽¹¹⁾. These services can combine automation, connectivity and data analytics to help people optimise appliance use, reduce inputs, and increase yields or income.

3.2.1. Smart smallholder agriculture

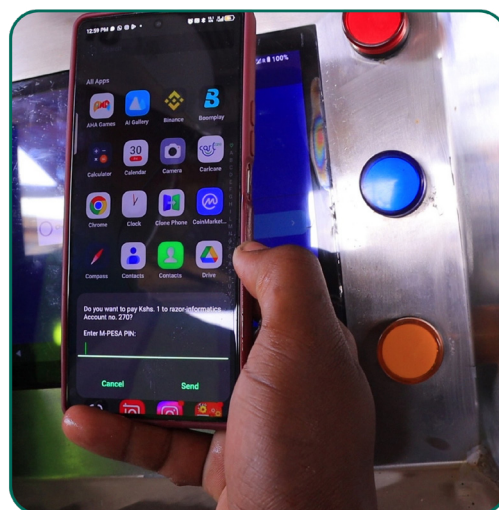
Smart agriculture refers to the integration of digital tools into farming systems to support more efficient, productive and sustainable practices⁽⁴³⁾. Through sensors in greenhouses, fields, pumps or solar dryers, farmers can receive real-time information about soil moisture, temperature, water flow and other parameters. This data can be used to automate irrigation, reduce fertiliser use, and optimise crop cycles. These systems not only reduce manual workload but also support more informed decision-making. This model of data-enabled service delivery is part of a broader shift towards ‘Farming-as-a-Service’, where providers offer not just equipment, but continuous support and tools to improve productivity⁽⁴⁴⁾.

Smart agriculture also plays a critical role in advancing food security and climate resilience, particularly in off-grid and low-resource settings⁽⁴⁵⁾. Off-grid solar-powered appliances paired with sensor-based monitoring systems can reduce water usage and preserve food quality. These tools reduce vulnerability to climate shocks by improving yields, minimising post-harvest losses, and enhancing year-round food availability. Smart agriculture supports more adaptive and robust food systems while promoting sustainable development.

3.3. Monitoring performance and ensuring reliability

Ensuring the reliable operation of solar appliances is a concern for funders, manufacturers, distributors and end-users. Remote monitoring is increasingly being used to assess the real-time status of appliances, providing early alerts for technical issues, and flagging operational anomalies that may compromise appliance effectiveness.

Remote monitoring systems are often linked to integrated customer service platforms or maintenance dashboards. These tools allow for more efficient deployment of technicians, reduced downtime, and improved customer support planning.



Savanna Circuit: paying by phone

For instance, the REMOT platform created by Innovex and used in a Kenyan school solar project helped identify overuse of systems, prompting targeted user training that extended system lifespan and improved outcomes⁽⁴⁹⁾.

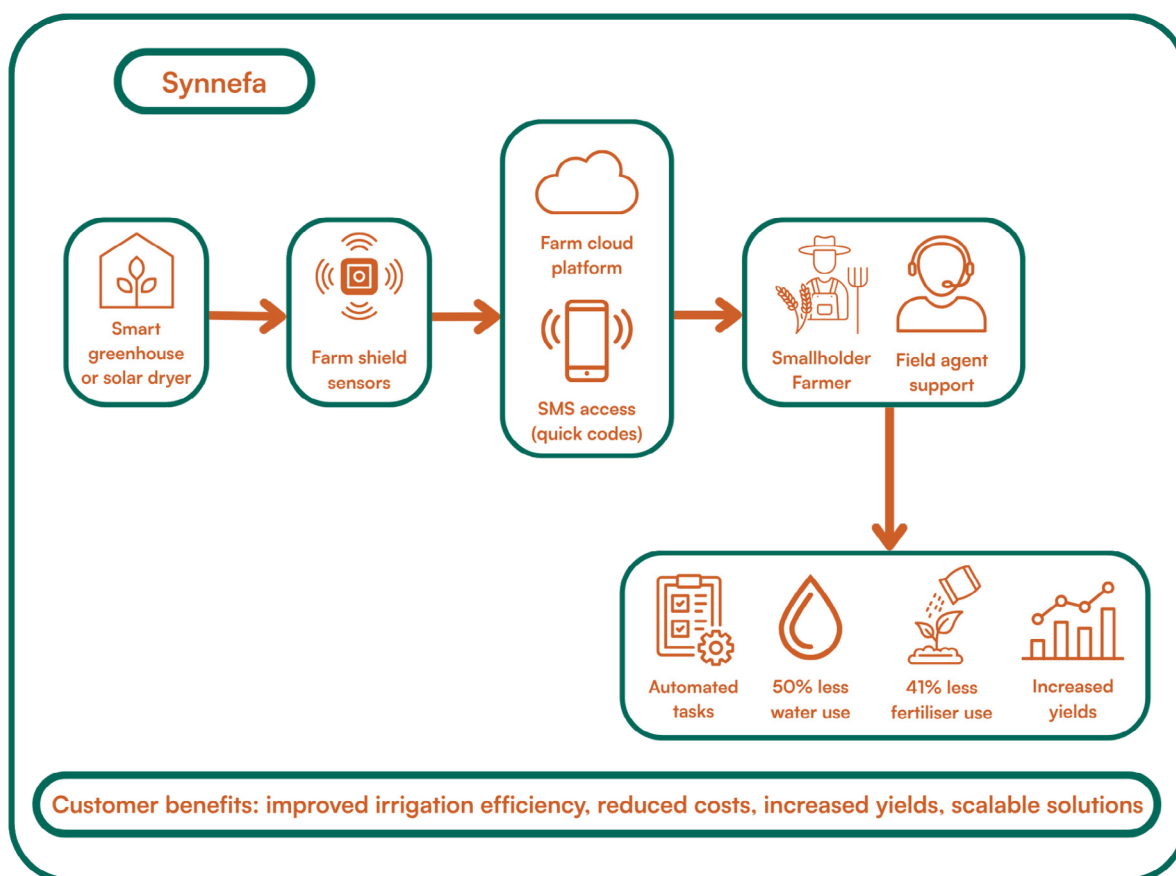
In India, Inclusive Energy partnered with the Indian National Dairy Development Board to install smart meters on biogas digesters used by 100 farmers in Bihar. Data from the meters highlighted usage patterns and technical issues, enabling tailored advice and minor adjustments that led to increased gas availability from around six — 10 cubic metres over a 15-day period, giving households roughly 10 additional hours of cooking time⁽⁵⁰⁾. By embedding these systems within appliances or adding external sensors, companies can monitor key performance metrics, proactively respond to faults, and build a stronger understanding of how their appliances behave in real-world environments.

3.3.1. Repair and maintenance

Appliance reliability is not just about detecting faults; it is about preventing them. Remote monitoring plays a role in shifting from reactive to proactive maintenance, enabling providers to predict failures, schedule technician visits efficiently, and offer better after-sales service. The off-grid appliance sector is beginning to adapt predictive maintenance practices from industrial and healthcare contexts, where continuous monitoring is used to prevent breakdowns and reduce lifecycle costs. For instance, in medical equipment or manufacturing plants, remote diagnostics are used to trigger repairs before equipment fails, a model now being piloted in solar pumping, refrigeration, and milling⁽²³⁾. This can help distributors identify common faults and improve availability of spare parts, often through providing alerts to end-users (case study 3).

The increasing prevalence of smart devices may also introduce challenges for reparability. When appliances are sold through PAYGo and Energy-as-a-Service business models, distributors want to ensure they are tamper-proof⁽⁵¹⁾, but this can prevent end-users from repairing the appliances themselves⁽⁵²⁾.

Case study 2 - Synnefa: Increasing the efficiency of smallholder farming



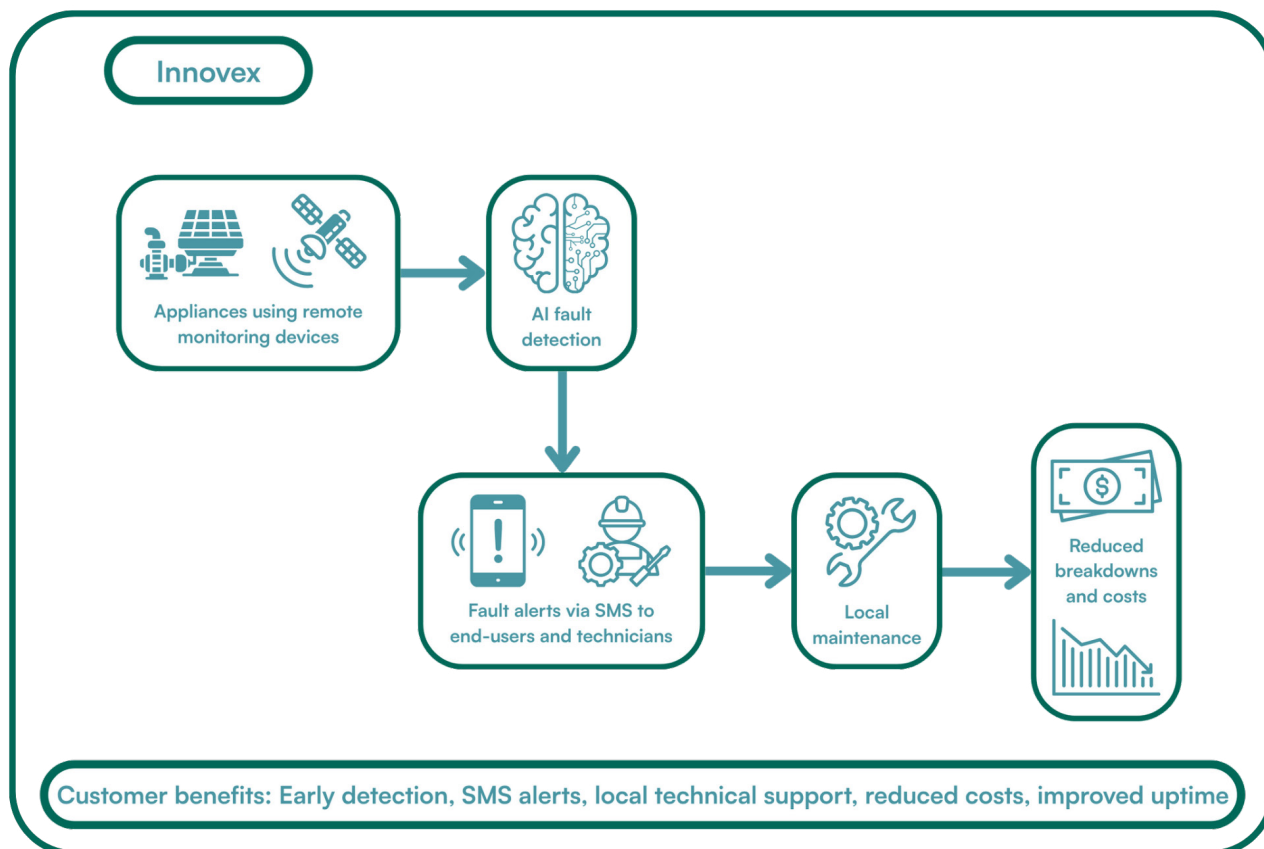
- **Company type:** Manufacturer and distributor of smart farming equipment
- **Technology:** Smart greenhouses with irrigation, solar dryers and farm management equipment and software
- **Location:** Based in Kenya, providing services in Kenya, Rwanda, Uganda, Tanzania, Ghana and Zambia.

Synnefa has developed Farm Shield — a solar-powered remote monitoring and automation system designed for greenhouses and solar dryers. Synnefa also offers the Farm Cloud platform for farm management — including inventory management, record-keeping, and financial tracking. Farmers can choose to purchase equipment upfront or to rent per month, with online services provided as part of their purchase. Synnefa has integrated remote monitoring into its farming solutions, enabling farmers to make data-driven decisions, improve irrigation efficiency, reduce input costs, and increase yields⁽⁴⁶⁾. The Farm Shield system uses sensors to measure soil moisture, temperature, nutrients, water flow, carbon dioxide, ammonia, and humidity. Data is transmitted using GSM or satellite communication and stored on the Farm Cloud platform.

This platform enables automation of irrigation and drying, which reduces guesswork and manual labour for farmers. This integration has allowed farmers to remotely monitor and control farm conditions, leading to improved productivity and optimised input usage, such as reducing water usage by 50% and reducing fertiliser application rates by 41%⁽⁴⁷⁾. The system is scalable, so can be adapted for different farm sizes and monitoring needs. Synnefa is currently developing smart greenhouse solar dryers, funded by the Efficiency for Access Research and Development Fund.

Synnefa has developed its platform in collaboration with farmers so that data is translated into outputs that are easily understood. Farmers can struggle to see the long-term value of remote monitoring, so Synnefa conducts training and awareness raising programmes. Government incentives for data-driven farming would enable Synnefa and other companies to support farmers to improve efficiency and sustainability. Another challenge is a lack of digital literacy, including farmers who don't have access to smart phones. Synnefa has enabled 'quick codes' so farmers can manage their farm via text message⁽⁴⁸⁾ and also has field agents who provide in-person advice and support, alongside on-boarding sessions during installation and remote customer support for troubleshooting.

Case study 3 - Innovex: Predicting appliance faults and maintenance issues



- **Company type:** Remote monitoring hardware and software provider
- **Technology:** Work across multiple appliances including solar water pumps, refrigerators, cold rooms and mills
- **Location:** Based in Uganda, providing services in Uganda, Kenya, Rwanda, Tanzania, Malawi, Nigeria, Mali and Nepal

Innovex offers its clients a range of remote monitoring services, including PAYGo functionality and quality monitoring. A recent grant from the Efficiency for Access Research and Development Fund has enabled the company to complete research into common faults in solar water pumps, refrigerators and mills, and how these could be predicted using remote monitoring and AI. Key challenges Innovex aimed to address include high maintenance costs, lack of access to spare parts, and poor adherence to maintenance schedules. Through direct engagement with end-users and distributors, Innovex identified specific issues, such as blocked impellers in solar pumps, thermostat failures in refrigerators, and user-related faults like inserting hot food into freezers. The company used this data alongside laboratory testing to develop AI models capable of detecting faults in real time. This project has enabled to identify eight different faults in solar refrigerators and water pumps, compared to only two faults prior to this project. End-users can address half of these warnings, such as reducing excessive load.

In several cases, local technicians, or trained end-users, will be able to maintain appliances, for example when the sieve in a solar water pump has been blocked or worn out. These models have now been deployed in an alert system, providing end-users with simple text messages identifying faults and offering recommended actions. For example, a farmer might receive a text indicating a likely pump blockage, prompting them to get this cleared by a local technician before a full breakdown occurs. Similarly, a shopkeeper could be alerted that their refrigerator is overloaded and empty it, reducing the risk of compressor failure.

While challenges remain, such as incomplete data sets and the need for longer-term field validation, Innovex are already enabling end-users and companies to address issues before appliances fail. There are some early insights from companies who are using alert systems in their off-grid appliances. In its first quarter using the technology, Aptech Africa has seen a 10% reduction in the need for in-person visits to fix water pumps, with improved up-time for end-users. Solar Cooling Engineering identified preventative maintenance which meant a cold room compressor did not need to be replaced, at a cost of over USD 1,000.

The company's next steps include partnerships with appliance manufacturers, such as Koolboks and ennos, to expand datasets and improve model adaptability. They also plan to explore integrating large language models to improve communication and end-user support across their platform.

3.3.2. Monitoring in cold storage

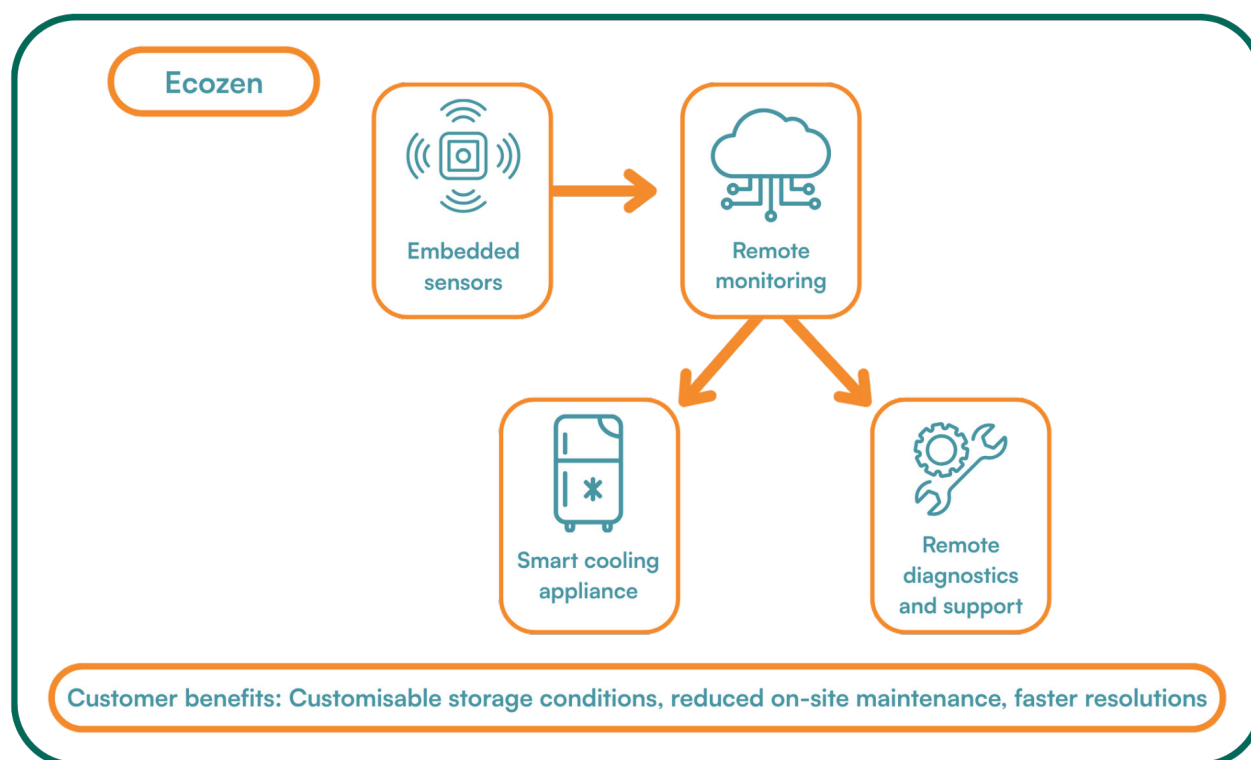
Ensuring the quality and consistency of appliance performance is essential across many sectors but is particularly critical for cold storage applications in agriculture, health and fisheries. In these contexts, even short-term equipment failures or temperature deviations can lead to spoilage, financial loss or health risks.

Remote monitoring allows companies to track appliance performance, such as internal temperature, humidity, or compressor function continuously, and to intervene before failures occur. This helps maintain product integrity, reduce food waste and increase trust in decentralised cold chain systems. In the cold storage sector, Ecozen⁽⁵³⁾, Solar Cooling Engineering⁽⁵⁴⁾ and Adili Solar Hubs⁽⁵⁵⁾ are using remote monitoring to ensure the optimal operation of their cold storage units.

These technologies help maintain the correct temperature and humidity levels, which are crucial for preserving perishable goods, reducing post-harvest losses and improving food security. Maintaining the integrity of cold chains is essential for sectors such as agriculture and healthcare, where the viability of products depends on consistent temperature control. Remote monitoring enables companies to maintain and optimise temperature-sensitive operations, helping to reduce spoilage and ensure reliable service delivery across last-mile locations. It can provide reassurance about the quality of appliance service to healthcare providers and produce buyers.

In the agricultural sector, technologies that maintain temperature and humidity conditions help reduce post-harvest losses and ensure the safety and shelf life of produce. For example, Promethean Power's cold chain solutions for India's dairy sector incorporates remote monitoring to manage temperature fluctuations and optimise energy use. Promethean has implemented a user-friendly dashboard so end-users can monitor the temperature throughout the cold chain⁽⁵⁶⁾.

Case study 4 - Ecozen: Optimising cooling solutions and providing customer support



- **Company type:** Manufacturer and distributor of solar pumps, refrigerators, cold rooms and freezers with integrated remote monitoring.
- **Technology:** Cooling and irrigation
- **Location:** Based in India, providing services globally.

By embedding sensors and communication modules within its cooling appliances, Ecozen⁽⁵³⁾ can remotely track the performance of their refrigerators and freezers.

People using their devices can pre-set temperature and humidity settings based on the requirements of the produce they are storing. Ecozen's system enables real-time adjustments and diagnostics, optimising appliance operation and reducing the need for on-site maintenance. The data collected from these devices is transmitted to a centralised dashboard, where Ecozen's technical team can monitor performance metrics, detect anomalies, and implement corrective actions remotely. This enables the company to improve customer service support, such as planning repair and maintenance schedules for technicians.

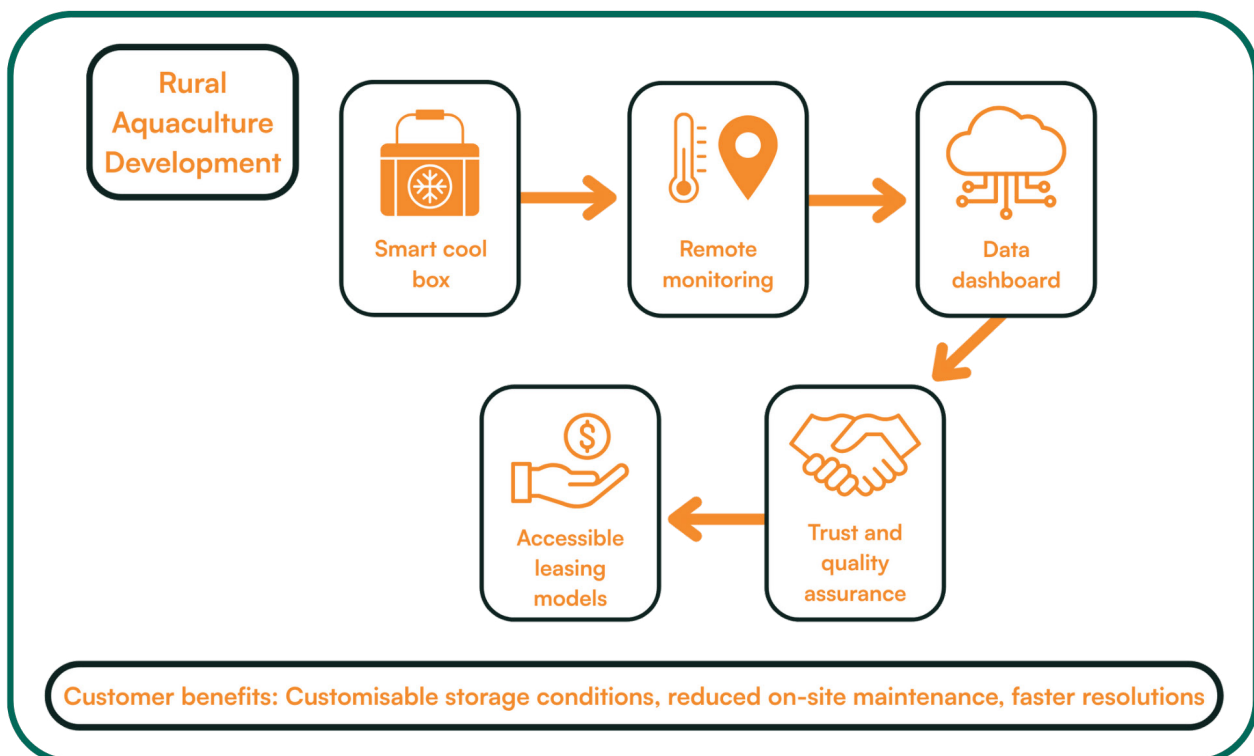
3.3.3. Remote tracking

In addition to monitoring static appliances, remote monitoring can be used to track mobile or distributed assets such as transportable cold boxes, rental appliances or portable productive-use equipment. These systems combine environment sensing with geolocation data to provide a full picture of how and where appliances are used. If a customer stops repaying for a device, remote tracking can help a company or distributor reclaim it.

Tracking is particularly valuable in supply chains for perishable goods like fish or fresh produce, where trust, traceability and quality assurance are essential. Real-time tracking with sensors can show whether an appliance has been exposed to excessive heat, has taken an unplanned route, or has been tampered with. It can provide data for route optimisation or asset management.

These kinds of tracking systems expand the role of remote monitoring from appliance optimisation to supply chain transparency and stakeholder accountability, which are key factors for value chain resilience.

Case study 5 - Rural Aquaculture Development: Improving transparency and trust in fish value chains



- **Company type:** Providing services to smallholder fish farmers
- **Technology:** Cool boxes for transporting produce in the fish value chain
- **Location:** Uganda

RAD (Rural Aquaculture Development) is developing cool boxes equipped with remote monitoring systems to track location and temperature. This provides quality assurance and improves trust among stakeholders in the fish supply chain. These boxes are designed using phase change materials for cooling to tackle challenges around the transport of fish. The remote monitoring systems include GPS and temperature tracking, allowing distributors to monitor the transportation of their produce in real-time, which helps with planning and business decision-making.

The system uses SIM cards and battery packs to transmit data via the cloud to a dashboard. This setup includes temperature sensors inside and outside the container and a GPS antenna. This increases the transparency of transportation, enabling a distributor to know if the cool box has been left in the sun, or if the driver has taken a different route, for example. RAD hopes to build trust among buyers and sellers by providing quality assurance about the location and temperature of products. RAD has faced several challenges in implementing these technologies. The company explored the use of open-source tools but found these did not meet their needs. The cost of the current dashboard (GBP 100 per IoT box per month) has been a significant hurdle. Ensuring the robustness of devices and preventing tampering have posed difficulties. RAD is exploring different business models, such as direct leasing and shopkeeper-based models, to make services more accessible and sustainable for smallholder farmers.

3.4. Generating insights for companies and the sector

Remote monitoring is not only a tool for managing hardware, but also a source of operational and behavioural data. Beyond enabling innovative financing models, remote monitoring systems provide rich data that can enhance customer understanding, improve product design, and support targeted service delivery. Analysis of operational data can inform the design of future products. Companies can identify failure points, inefficiencies, and suboptimal usage behaviours.

3.4.1. End-user insights

Remote monitoring generates insights into how appliances are used in the field - what times of day, under what conditions, and for which purposes. This helps companies differentiate between assumptions made in laboratory testing and real-life user behaviour. For example, Ecozen's monitoring of cold storage units has revealed customer preferences for specific temperature settings and how usage fluctuates by season or region.

"Data helps companies refine inventory management, marketing efforts, and distributor support."



Coffee drying in a solar greenhouse

Photo credit: Synnefa

Remote monitoring enables distributors to assess the performance of products in different environments or user segments. Data can reveal, for example, whether a particular solar mill is more suited to certain regions or if a cold storage unit is underutilised. This helps companies refine inventory management, marketing efforts, and distributor support. It can also mean they can provide services better tailored to end-users. Customer insights from remote monitoring systems can inform research, donor strategies, policy development, and sector coordination. By contributing data to shared platforms or studies, companies can help identify trends in appliance adoption, usage, and durability. Initiatives such as Efficiency for Access are already using these insights to inform procurement standards, funding decisions, and design guidelines for solar appliances. As technology matures and the solar appliance sector grows, investing in shared data systems and open-access research will be key to scaling the benefits of remote monitoring across the global appliance ecosystem.

Agsol's partnership with Welthungerhilfe shows how remote monitoring can improve appliance performance and user experience. The company's solar-powered grain mills, equipped with remote monitoring, track when and how often the machines are used. The data revealed regional differences in usage and allowed Agsol to fix technical issues quickly and adapt their training and business models to local needs. Users reported saving an average of 2.5 hours per day compared to manual milling, showing how data-driven insights can lead to more reliable service and greater value for users⁽⁵⁷⁾.

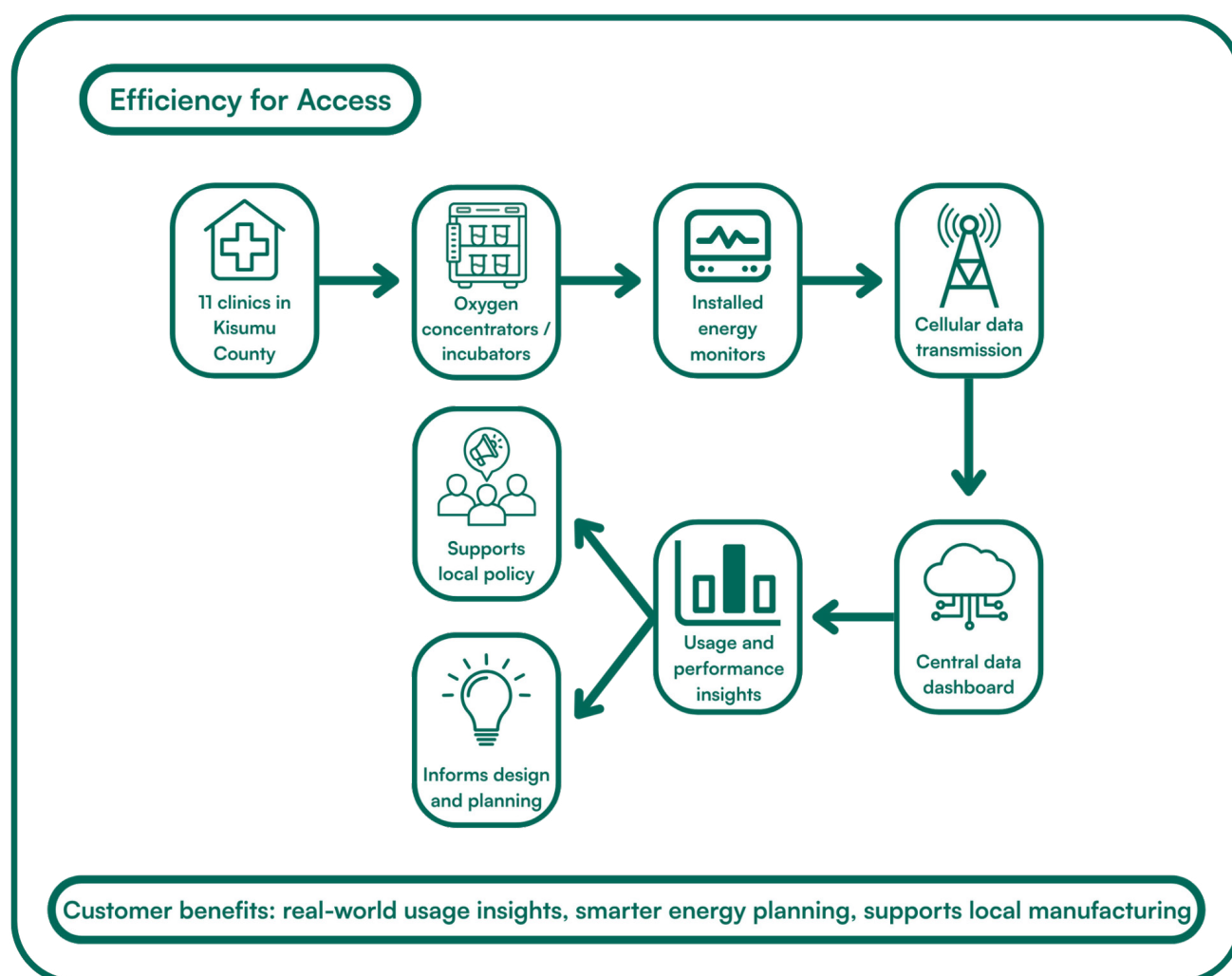
3.4.2. Intersections with other sectors

Remote monitoring systems for appliances can intersect with sectors such as health, agriculture, and water through tracking resource use, measuring impact, and supporting infrastructure planning. One example is the Kenya RAPID project, where sensors were installed on solar-powered borehole pumps to monitor water system functionality and usage. This data, transmitted to a web server, allows county staff to efficiently manage water resources, reducing maintenance costs and downtime. The project has enhanced agricultural productivity on previously infertile land and improved pump uptime from 70% to over 99%⁽⁵⁸⁾.

"As technology matures... investing in shared data systems and open-access research will be key to scaling the benefits of remote monitoring."

The following case study from Efficiency for Access shows how remote monitoring can be used to evaluate field performance of appliances. This can be used to guide procurement and system design and inform the design of government policy.

Case study 6: Understanding healthcare appliance usage patterns



Efficiency for Access is exploring how remote monitoring can generate actionable insights about healthcare appliances in under-resourced settings. Building on our 2021⁽⁵⁹⁾ report that highlighted challenges with medical device suitability and durability, this new initiative focuses on real-world usage and performance data from clinics in Kisumu County, Kenya.

Through a partnership with Sustainable Energy for All, CLASP, co-Secretariat of Efficiency for Access, remotely monitored the electricity consumption of three key appliance categories: oxygen concentrators, autoclaves, and incubators or resuscitators. These appliances are essential in primary healthcare facilities but are often underused due to power supply limitations or misaligned design specifications⁽⁶⁰⁾. To collect performance data, CLASP installed energy monitors on appliances across 11 clinics. These devices, provided by A2EI, transmit data via cellular networks and can operate independent of appliance brand or model.

The project aims to validate whether manufacturers' stated energy consumption figures hold up in clinics with weak-grid or off-grid electricity. Early findings show that voltage inconsistencies and insufficient power infrastructure limit appliance use.

By analysing energy consumption patterns, the research aims to inform the design of more appropriate and efficient devices, guide the sizing of decentralised renewable energy systems, and advocate for local manufacturing of context-specific appliances. It also provides insights into how and when medical appliances are used.

This work highlights the broader potential of remote monitoring to improve health service delivery, support energy planning, and inform policy design.



Engineers conduct rigorous testing on parts for use in remote monitoring
Photo credit: Innovex

4. UNLOCKING THE POTENTIAL OF REMOTE MONITORING: BARRIERS AND HOW TO MOVE FORWARD

Introduction

The implementation of remote monitoring technology in solar appliances presents numerous benefits, such as improved operational efficiency, predictive maintenance and repair, and improved customer engagement and satisfaction. However, adopting these systems also introduces a range of challenges. These challenges vary depending on the technology, the users, the context, and the companies implementing them.

4.1. Making remote monitoring work for end users

4.1.1. Usability and acceptance

For many end-users, especially those with limited digital literacy, remote monitoring systems can be challenging to navigate. If the system interfaces are overly technical or difficult to understand, users may not fully engage with the data provided, leading to missed opportunities for optimisation or preventing appliance malfunctions. In many regions, smart phone ownership is limited, so systems that require the use of apps or cloud-based platforms may not be accessible. To address this, companies like Innovex are integrating solutions that can communicate data through text messages.

Recommendations

Off-grid appliance companies

- Engage users in the design of solutions
- Develop low-tech interfaces such as text-based alerts
- Consider working through trusted intermediaries like field agents, farmers' cooperatives or community organisations to connect with end-users
- Use insights from remote monitoring to improve product design, identify maintenance trends, and evaluate approaches to customer support

Funders

- Finance pilots to test inclusive user interface options and offline-compatible systems
- Support community-based training and digital access initiatives to complement system design

4.1.2. End-user awareness and training

End-users may not always be aware of the capabilities of remote monitoring systems or how to act on the insights provided. Training is essential to ensure that users can effectively interpret the data and respond appropriately to alerts, whether it's for adjusting appliance settings or doing preventive maintenance.

Recommendations

Off-grid appliance companies

- Offer onboarding and ongoing training or guidance to end-users
- Create user-friendly customisable resources informed by user needs assessments and testing, such as guides, dashboard and tailored reports

Example: Promethean Power provides cooling services in milk value chains in India — supporting dairies, farmers, co-operatives, buyers and transporters. The company have improved the usability of its platforms by implementing user-friendly dashboards, offering customisation options, integrating multiple products and enabling users to create detailed charts⁽⁶¹⁾.

4.1.3. Trust and transparency

As more data is collected from users, there is concern around how it is stored, shared, and used⁽⁵⁾. Ensuring that users' data is securely handled, not misused, and follows local data protection laws is crucial. It should also be clear whether data sharing is optional or compulsory.

Users may not be comfortable that appliances that can be remotely controlled or shut off, particularly if they are not fully informed about this at the time of purchase. Many contracts are signed without users understanding the extent of data collection or control, highlighting the importance of informed consent. Recent research from 60 Decibels showed issues with trust around appliances being locked or removed and highlighted the importance of consumer protection and good practice communication⁽⁶²⁾.

As remote monitoring systems collect vast amounts of operational and personal data, companies must ensure robust security measures are in place to protect against data breaches, unauthorised access, and interception of communications. Companies must comply with data privacy regulations (which vary across different countries) alongside safeguarding customer trust.

Companies must ensure transparency about their ability to remotely control appliances and how data collected from remote monitoring will be used. Users may feel disempowered or exploited or data may be used without their consent.

Recommendations

Off-grid appliance companies

- Clearly communicate data use policies in clear and simple terms and in local languages
- Follow the General Data Protection Regulations (GDPR)⁽⁶³⁾ or equivalent local standards for data protection
- Adopt and promote the GOGLA Consumer Protection Principles⁽⁶⁴⁾
- Use consent-based data sharing models, such as offering opt-in options for data sharing, aligning with best practices in data protection.
- Use secure encryption for data, and anonymise data where possible
- Conduct regular privacy audits and update policies

Public sector actors

- Promote alignment with international consumer protection and privacy standards



Workers watering crops. Photo credit: Simusolar

4.2. Building reliable and adaptable technology

4.2.1. Connectivity

One of the primary technical challenges for remote monitoring technology is ensuring reliable connectivity, especially in remote and rural areas⁽⁴⁾. Around 350 million people globally live in areas without mobile broadband coverage — these communities are

predominantly rural, low-income, and sparsely populated⁽⁶⁵⁾.

Many off-grid regions suffer from intermittent or weak GSM signal, making it difficult to transmit data in real-time. Satellite connections, which have much higher coverage, are very expensive. A lack of connectivity may lead to distributors or agents focusing their efforts in areas with signal, causing further marginalisation of last mile communities.

Recommendations

Off-grid appliance companies and remote monitoring service providers:

- Explore low-cost solutions that work in locations with low or intermittent connectivity, such as:
 - Hybrid data models that combine local storage with cloud options. This can enable systems to store and forward data when connectivity is lost / returns
 - Enable Bluetooth/RFID data pick-ups by field staff or users' phones
 - Consider global sims which can work across different networks⁽⁶⁶⁾

Funders

- Support pilot solutions which test different transmission modes, such as the GSMA Innovation Fund⁽⁶⁹⁾

Governments

- Include off-grid digital inclusion in rural communication strategies
- Research shows that mobile network coverage has a positive effect on poverty reduction — driven by positive impacts in participation in labour markets⁽⁷⁰⁾

Example: Simusolar designed an IoT controller 'PAYG Bridge' for areas with no mobile connectivity^(3,67). Alongside its solar water pumps, Simusolar provides farmers with a smartphone, which transmits the data when the farmer is in a location with signal. This enables Simusolar to offer financing where a lack of connectivity would normally limit equipment control and monitoring, which are required for obtaining financing for assets. Providing farmers with a smart phone also enables them to learn about farming techniques, stay updated on market prices and share farming information.

Simusolar has worked with the International Institute for Environment and Development on this project to map out gender differences and identify how they can target more women farmers⁽⁶⁸⁾.

4.2.2. Complexity of customising systems

Remote monitoring systems often need to be tailored to meet the specific requirements of different appliances and sectors. Appliances vary not only in their technical specifications, such as voltage, current type (AC/DC/three-phase), and operating conditions, but also in how data is collected and interpreted. Designing systems that can manage a combination of parameters like power usage, internal temperature, and motor performance across diverse use cases can be technically demanding and resource intensive. This level of customisation slows down deployment and increases the cost and complexity of implementation, especially for companies working across multiple appliance categories and in different countries.

While some monitoring tools can be add-ons for appliances, these solutions have limitations. They must be unobtrusive and must not interfere with normal operation, which can be a challenge for larger or more sensitive equipment. Although external or retrofit devices are useful for pilot studies, impact evaluations, and early-stage research, they are rarely viable for large-scale or long-term monitoring due to costs and operational challenges (such as being able to be unplugged manually).

Fully integrated monitoring systems offer better performance and long-term cost savings but can drive up initial production costs due to the need for enhanced robustness, environmental resistance, and tamper-proofing. These requirements are important for off-grid settings, where appliances may be exposed to dust, moisture, and handling by non-specialists.

Recommendations

Remote monitoring service providers

- Development of tools which work in different settings, such as modular plug-and-play sensor kits for pilot testing

Whole sector

- Partnerships between appliance companies and service providers to integrate remote monitoring during manufacturing to reduce costs
- Support for open-source toolkits that can provide a low-cost entry point to remote monitoring

For companies with limited resources or those operating in high-variation markets, finding scalable, adaptable, and cost-effective monitoring solutions remains a challenge.



Woman being shown how to use remote monitoring application in field with water pump in operation. Photo credit: Simusolar

4.3. Strengthening the business case for remote monitoring

Implementing remote monitoring requires upfront investment in hardware (sensors, communication equipment) and software (data management systems, data analysis and use of AI). Companies must balance the initial costs with long-term savings from predictive maintenance, improved customer satisfaction (and retention), and increased operational efficiency.

"While some monitoring tools can be add-ons for appliances... they must be unobtrusive and must not interfere with normal operation, which can be a challenge for larger or more sensitive equipment."

4.3.1. Understanding of costs and benefits

Calculating the return on investment for these systems can be complex, particularly for smaller companies or for emerging markets or technologies. There is a need for data and research which demonstrates the cost benefits of different applications.

Recommendations

Funders and industry associations

- Funders and industry networks should take the lead in collecting and disseminating case studies and cost-benefit analyses that illustrate successful remote monitoring deployments. This would help new market entrants and smaller companies to justify investment and reduce duplication of early research efforts
- Funders should provide long-term support and patient capital to help appliance companies test and iterate new approaches, such as AI-enabled fault detection or dMRV for climate finance

Off-grid appliance companies:

- Strengthen business cases by integrating additional applications of remote monitoring, and sharing lessons learned with the sector

In the absence of shared standards, users may face higher costs, limited support, and shortened product lifespans, which undermines both affordability and long-term impact.

Recommendations

Off-grid appliance companies

- Design products with open hardware interfaces and standardised communication protocols to ensure long-term flexibility and reduce lock-in for end users
- Engage with existing interoperability initiatives to align with emerging standards and influence their development through field insights

IoT and software providers

- Ensure platforms support integration with open interfaces and common data formats to enable interoperability with third-party tools
- Develop modular systems that allow customers to scale up functionality, including from basic monitoring to predictive analytics, without needing to replace the whole system

Governments and policymakers

- Embed interoperability requirements in public procurement, subsidy programmes, and results-based financing schemes to drive standard adoption across off-grid appliance markets
- Support the development of national or regional data and hardware standards for off-grid energy systems, coordinated with sectoral bodies such as GOGLA

Funders and industry associations

- Fund open-source tools, shared infrastructure, and standards development efforts that reduce technical and cost barriers for new market entrants
- Convene cross-sector stakeholders to harmonise interoperability efforts across the appliance, IoT, and finance sectors ensuring alignment with broader digital public infrastructure and energy access goals

4.3.2. Interoperability

Without shared standards, remote monitoring risks becoming a fragmented landscape of incompatible systems - slowing innovation, increasing costs, and locking users into specific platforms. As companies look to integrate monitoring with finance tools, agricultural data platforms, and customer-facing apps, standardisation of hardware interfaces, communication protocols (e.g., MQTT), and APIs becomes critical. This would allow data sharing across devices and services, enable more flexible product ecosystems, and reduce long-term dependency on single vendors.

"In absence of shared standards, users may face higher costs, limited support, shortened product lifespans."

Interoperability also matters for end users, who benefit from the ability to mix and match components, upgrade equipment over time, and avoid being locked into a single provider's services. Standardised connectors and communication protocols can enable users to replace faulty parts (such as sensors), add new functionalities, or connect to third-party services (such as integrating climate data) without needing to overhaul their entire system. This flexibility helps ensure that off-grid users can adapt technologies to their evolving needs and budgets, while also helping to foster more competitive, user-friendly markets.

To address some of these interoperability and integration challenges, initiatives like GOGLA's Connect Initiative⁽⁷¹⁾ are working toward the standardisation of hardware and communication protocols. This includes the development of a universal family of connectors for 12V solar home system (SHS) kits, standardised electrical characteristics (e.g., voltage and current), and open communication protocols such as OpenPAYGO Link (developed by Solaris) and the Nexus Channel for PAYGo activation and device control (developed by Angaza). These standards aim to improve device compatibility, streamline data exchange, and enable greater scalability across the off-grid energy sector. Public and private sector collaboration is needed to advance interoperable platforms⁽⁷²⁾ and shared interfaces. This would reduce the technical burden on appliance providers and allow data to be aggregated more easily for impact reporting, results-based financing, and cross-sector learning.

Recommendations

Off-grid appliance companies

- Explore pooling emissions reductions across similar devices and projects. Aggregators like the Mirova SunFunder Special Purpose Vehicle model offer a viable way to increase scale, reduce transaction costs, and attract investors through bundled carbon credit portfolios⁽⁷³⁾

IoT service providers

- Support companies by offering data aggregation services and providing services that meet dMRV criteria

Broader sector

- Support early-stage companies to navigate the complexities and upfront costs associated with entry into carbon markets⁽⁴¹⁾
- Carbon credit methodologies should recognise digital monitoring, reporting and verification and develop standardised baselines for solar appliances
- Implement robust standardised baseline studies and a consolidated solar appliance carbon methodology⁽⁴⁰⁾

4.3.3. Carbon credits

The current carbon credit landscape poses significant challenges. Existing methodologies for calculating emissions reductions are not tailored to the nuances of solar appliances, leading to potential underestimation or overestimation of their environmental impact. The verification processes required to certify carbon credits can be complex and costly, particularly for small-scale projects.

"Public and private sector collaboration is needed to advance interoperable platforms and shared interfaces. This would reduce the burden on appliance providers and allow data to be aggregated more easily."

The process of certification and Monitoring, Reporting, and Verification (MRV) is costly and complex, especially for smaller companies. Traditional methods are not suitable for solar appliances. Although remote monitoring offers a pathway to lower-cost, real-time digital monitoring, reporting and verification (dMRV), they are not yet widely embedded in methodologies.



A remote monitoring device in operation inside a solar dryer

Photo credit: Synnefa



A worker sorts vegetables outside of a walk-in cold room
Photo credit: CoolHubs

5. SHAPING THE FUTURE OF REMOTE MONITORING: ROLES AND STRATEGIC PRIORITIES

The barriers outlined in the previous section show that realising the full potential of remote monitoring will require coordinated, sustained effort across the off-grid solar ecosystem. This is not just a technical or operational challenge - it's a strategic opportunity. Remote monitoring can deliver significant value to companies, users, and the wider sector, but only if different actors take aligned and proactive steps.

This section outlines how the private sector, funders and investors, and policy stakeholders can contribute to that shared vision - tailored to where they are on the adoption journey and what levers they have to shape the future.

5.1. Companies established using remote monitoring

These companies are already integrating remote monitoring into their products and services. They need support to:

- Expand applications of remote monitoring, using insights to improve their products and services to customers
- Continue to embed user-centred design principles, ensuring interfaces are simple, consent is clear, and training is accessible
- Implement best practice on consumer and data protection
- Align with emerging carbon credit methodologies and dMRV standards to access finance
- Share lessons learned and common tools with peers to accelerate sector-wide innovation
- Participate in joint innovation initiatives (e.g. interoperability, universal dashboards, AI-powered diagnostics)

Distributors are likely to evaluate remote monitoring based on its impact on outcomes such as sales growth, customer satisfaction, repayment rates, or reductions in after-sales costs - rather than technical specifications alone. Manufacturers of off-grid appliances need to communicate this impact clearly to distributors so they can make informed purchasing decisions.

5.2. Companies new to remote monitoring

For companies just beginning to explore remote monitoring, more practical guidance is needed. This report provides a starting point, but additional tools would help, such as a supplementary toolkit to help companies assess costs, integration pathways, and relevant technology options.

However, this is a constantly evolving ecosystem. There is a need for clear, up-to-date information in changes in technology and policy.

5.3. Remote monitoring service providers

Remote monitoring service providers are central to the functionality, scalability, and affordability of digital monitoring systems in the off-grid appliance sector.

To support the sector's growth, service providers should:

- Develop interoperable tools that can be adapted across a range of appliances and geographies
- Support interoperability and open standards to ensure that systems can integrate and scale
- Provide aggregation services to support carbon finance and third-party reporting
- Balance innovation with inclusivity, ensuring tools are usable in low-connectivity environments and adaptable for different user segments



Savanna Circuit device screen - operating remotely

5.4. Industry associations

Industry associations can play a convening role in enabling shared infrastructure and strengthening the ecosystem:

- Promote and support interoperability, alongside open-source monitoring tools and non-proprietary solutions
- Encourage participation in shared platforms for emissions tracking, results-based finance, and user data pooling

5.5. Funders

Funders have a critical role in catalysing the remote monitoring ecosystem and setting it on the right path to scale. Grant funding for remote monitoring can help companies to improve business operations and enable access to finance, reducing upfront costs. Their support is needed not only to fund specific pilots or companies, but also to shape a market that is inclusive, efficient, and aligned with long-term climate and development goals.

"Grant funding for remote monitoring can help companies to improve business operations, reducing upfront costs."

- Provide long-term support and patient capital to help companies test and iterate on innovative models and technologies
- Invest in shared infrastructure and open-source tools to reduce duplication and enable access for smaller companies
- Facilitate cross-sector learning, including between agriculture, energy, health, and communications sectors
- Use outcome-based financing and innovation challenges to incentivise progress on usability, predictive maintenance, and dMRV

- Support standardisation efforts including shared platforms and carbon accounting frameworks
- Harmonising data requirements and allowing companies to use the same monitoring data to co-deploy different types of funds - for instance combining receivables financing or debt with RBF.

5.6. Policy makers and regulators

While policy and regulation are important enablers, remote monitoring in solar appliances is still an emerging area. Policymakers and regulators should focus on creating the enabling conditions for future alignment and growth.

- Support pilots to test how dMRV can be integrated into national climate reporting and verification systems
- Invest in rural connectivity and digital inclusion strategies to expand the infrastructure needed for remote monitoring
- Promote awareness of data rights and privacy standards, aligned with international best practice but adapted to local contexts
- Monitor developments in the sector to identify when and how supportive regulation should be introduced



Collecting products from an operating off-grid refrigerator

Photo credit: Amped Innovation



Where are we now?

What's the current state of remote monitoring technology in the appliance sector?

- Remote monitoring now underpins models like Pay-as-you-Go and Energy-as-a-Service, helping companies manage systems more effectively.
- Remote monitoring enables real-time diagnostics and provides valuable data on how appliances are used in the field.
- Adoption is still patchy—often limited to pilots or a few frontrunner companies with resources.
- Key barriers include poor connectivity, high costs, understanding of costs and benefits and customer protections and trust.

Where do we need to go next?

What roles can it play in scaling access, improving reliability, and unlocking finance?



- Remote monitoring can support inclusive financing, making appliances more accessible to underserved users.
- Remote monitoring can improve reliability and performance, helping build trust and reduce maintenance costs.
- Verifiable usage data can unlock new capital sources like carbon credits and results-based finance.
- Long-term, it can help create smarter, more efficient, and inclusive markets for off-grid solar appliances.



How do we get there?

What are the priority actions for companies, funders, and public sector enablers?

- The sector needs shared standards and open platforms to avoid fragmentation and duplication.
- Companies should be supported to embed monitoring into product design and business models.
- Service providers must prioritise affordability, interoperability, and usability across diverse contexts.
- Funders and policymakers should invest in infrastructure, open tools, and enabling regulation.

CONCLUSION

Where are we now?

Remote monitoring has evolved from a niche innovation to an enabler of progress in the off-grid solar appliance sector. It is already powering new business models such as Pay-As-You-Go and Energy-as-a-Service, enabling real-time diagnostics, and providing data that helps companies understand how their products are used in the field. However, its use is still uneven - often limited to pilot projects or concentrated among a few frontrunner companies. Technical, financial, and organisational barriers continue to limit broader adoption, especially in low-connectivity and lower-income markets.

Where do we need to go next?

Remote monitoring can help scale access by enabling inclusive financing models and improving appliance reliability. It can improve product design, reduce costs, and build trust with users. Crucially, it can unlock new sources of capital, such as carbon credits and results-based finance - by providing verifiable data on use and impact. In the long term, it can drive smarter, more efficient, and more inclusive markets for sustainable appliances.

How do we get there?

The sector must move beyond fragmented, proprietary approaches and invest in shared solutions and standards. Established and emerging companies alike need support to integrate remote monitoring into their business models and product development processes. Remote monitoring service providers should prioritise affordability, interoperability, and usability across contexts. Funders and investors must go beyond pilot support to shape the ecosystem by investing in infrastructure, open-source tools, and long-term innovation. Policymakers can lay the groundwork by supporting connectivity, digital rights, and regulatory frameworks that recognise digital monitoring and reporting.

Getting there will require coordination, investment, and a shared commitment to innovation that is grounded not only in technology, but also in the real needs of users, companies, and communities.

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A farmer checks on their remote
monitoring device

Photo credit: Synnefa



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