ENERGY CATALYST

AN ENERGY CATALYST SHOWCASE

Inclusive innovation: building resilient grid systems across sub-Saharan Africa

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About Energy Catalyst and this report

This research explores some of the key challenges in delivering stable, reliable grid and mini-grid services across sub-Saharan Africa. Drawing from a selection of Energy Catalyst-supported companies as case studies, it highlights innovation trends with the potential to address these challenges and distils insights to inform the wider energy access sector.

Energy Catalyst is an Innovate UK programme funded by the Foreign, Commonwealth and Development Office (FCDO) and the Department for Science, Innovation and Technology (DSIT) under the Ayrton Fund, part of the UK's International Climate Finance commitment. Through financial and advisory support, and by building strategic partnerships and uncovering new insights, Energy Catalyst accelerates the innovation needed to realise a just and inclusive clean energy transition across communities in Africa, Asia and the Indo-Pacific region.

Energy Catalyst aims to accelerate progress on Sustainable Development Goal (SDG) 7 by ensuring access to affordable, reliable, sustainable, and modern energy for all.

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Glossary

AC	Alternating current
Black start capability	The ability of a power source to start up independently without external grid power, enabling grid restoration after a blackout
Demand side management	Broad strategies to influence electricity use patterns, including efficiency measures, behavioural change, and tariff design
Demand side response	Real-time adjustment of electricity demand in response to grid signals, often incentivised to support system balancing
DC	Direct current
Flatten load curve	Reducing peaks and filling valleys in electricity demand to create a more stable and predictable load profile
Load shifting	Moving electricity use from peak to off-peak periods.
Mesh-grid	A decentralised grid architecture where multiple generation and storage nodes are interconnected, allowing flexible power flows and redundancy
Mini-grid	Typically a small-scale AC electricity network serving a defined community and includes generation, distribution and control systems. It can be grid-tied or off-grid
Nano-grid	A very small-scale DC electricity networking serving a small cluster of households or businesses from a solar panel and battery
Outage	A temporary loss of electricity supply
Peak shaving	Reducing electricity demand during peak periods
Prosumer	An energy customer who is also a producer

iStock, 2024

iStock, 2021

Executive summary

Reliability of electricity is vital for economic growth and climate resilience in sub-Saharan Africa, yet over 600 million people across the continent still lack meaningful access. Despite growing investment, grid and mini-grid services are often still intermittent, fragmented and inefficient, preventing affected communities and economies from reaching their full potential.

National grid utilities typically contend with high distribution and transmission losses (ranging between 15-30%) and frequent outages due to an inadequate maintenance of ageing infrastructure, poor load forecasting and insufficient generation capacity. Meanwhile, mini-grid developers struggle against operational constraints and integration challenges. Limited storage capacity and weak interconnections often make the integration of renewable energy sources into grids difficult, causing voltage instability and frequency fluctuations. Faced with unreliable service provision, users often resort to diesel generators, driving up both fuel costs and harmful emissions.

This report examines how innovative technologies, business models and planning frameworks are tackling challenges around grid and mini-grid stability and efficiency. It highlights five key trends in the current innovation landscape: whilst not a fully comprehensive survey of promising developments within this area, it provides a snapshot of the diverse solutions and innovations supported by Energy Catalyst.

To date, Energy Catalyst has invested over £160 million in inclusive energy projects spanning energy storage, smart grids, solar, cooling, cooking, appliances, bioenergy, agro-processing and digital platforms. For each key trend presented, this report showcases an Energy Catalyst-supported company taking pivotal steps towards improving the consistency and reliability of energy provision in sub-Saharan Africa.

This report will cover the following five themes:

Trend 1: Energy storage for resilience and stability

Battery Energy Storage Systems (BESS) balance supply and demand, enabling greater renewable penetration and reducing reliance on diesel. In mini-grids, they smooth supply and demand mismatches and support productive use, while in national grids they provide services such as frequency regulation and peak shaving (reducing high demand in peak periods). This trend is illustrated by **AceOn's HIGHESS system, a modular, portable second-life battery trailer** piloted in Nigeria and designed for humanitarian and rural deployment, as covered in greater detail within the case study.

Trend 2: Data-driven analytics, load management and forecasting

Smart planning and real-time monitoring are vital for operational reliability and financial sustainability. Advanced analytics enable predictive maintenance, dynamic load balancing and inclusive tariff design. **OrxaGrid is a company that specialises in grid analytics**. Its platform deploys sensors that capture analogue, digital and asset health data for cloud-based analysis.

iStock, 2019

Trend 3: Decentralised energy solutions supporting grid extension

Mini, mesh and nano-grids are now seen as strategic infrastructure rather than interim fixes. Designed to be 'grid-ready' they offer immediate relief to overstretched national systems while enabling modular expansion and future integration. **Nanoé is making significant strides in decentralisation.** Its PowerPath model in Madagascar has deployed over 3,000 nano-grids serving 12,000 customers across 600 villages, clustering them into mesh-grids that support communal loads and productive uses.

Trend 4: Demand side management, response and appliance efficiency

Demand-side management and response (DSM/DSR) systems reduce or shift peak loads through incentives, pricing signals, automated controls and predictive systems, while efficient appliances flatten load curves (reducing peaks and filling troughs in demand) and ease infrastructure strain. **Gridimp's intelligent demand-side response platform**, deployed in South Africa, automates control across batteries, appliances and electric vehicles, integrating solar forecasting and dynamic pricing.

Trend 5: Energy sharing and trading platforms for mini-grid optimisation

Peer-to-peer energy trading platforms optimise energy flows within distributed networks, reduce waste and improve financial viability. They also incentivise prosumers and support inclusive energy planning. Across an expanding portfolio of sites in Nigeria, **Ubuntu Energy's predictive load-sharing system** allows communities to buy and sell electricity within micro- and mini-grids, matching idle solar generation with local demand.

Technically and commercially, such trends will increasingly converge. For example, digital platforms enable usage monitoring, billing and expansion, while smart metering and modular electronics support interoperability and future grid integration.

Beyond technical gains, these developments promise to deliver tangible social and economic benefits: powering clinics, schools and small enterprises; enabling cold chains; and creating jobs in installation, manufacturing and entrepreneurship. Collectively, such improvements strengthen community infrastructure and expand opportunities for inclusive economic growth.

Whilst developing modular, interoperable technologies is an important driver of progress, improving the reliability of grid networks requires a broader strategic push from a range of stakeholders. Supportive regulation must formalise second-life battery use, peer-to-peer trading and mesh-grid development. Blended finance and results-based financing are needed to de-risk investment in underserved areas. Promoting appliance efficiency and productive use will strengthen the business case, while safeguards such as ethical sourcing and battery recycling are needed to ensure sustainability.

The Energy Catalyst case studies featured in this report show how targeted innovation can embed flexibility and intelligence into grid-based systems. Technology trends are evolving towards AI-driven grid orchestration, blockchain-based asset verification and localised energy markets. As these technologies mature, evidence from projects like those highlighted in this report will help to refine models, raise investment and shape enabling environments, paving the way for improved service delivery across grids and mini-grids.

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Nanoé, 2023

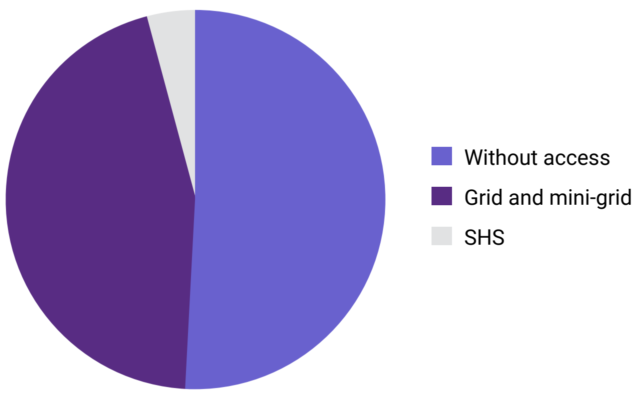
Introduction

This report examines how innovation is tackling the dual challenges of expanding electricity access and improving grid performance across sub-Saharan Africa (SSA). Through spotlighting Energy Catalyst-supported companies making significant strides in the sector, it demonstrates how advances in grid and mini-grid stability directly enable socio-economic development and strengthen climate resilience.

The access gap and the role of grids

Roughly 600 million people in SSA (about 50% of the population) still lack access to reliable electricity. For those who do have access, national grids and mini-grids provide over 90% of connections[1], making these systems the backbone of regional electrification efforts.

Figure 1: Electricity access in sub-Saharan Africa (source IEA, 2024)



Mini-grids[2] have emerged as a critical complementary infrastructure, particularly for remote communities with sufficient population density and energy demand. Analysis suggests that mini-grids represent the least-cost option for communities which match that profile, with the potential to serve up to 380 million people, roughly 60% of SSA's off-grid population[3]. Increasingly, developers are deploying mini-grids even in grid-connected regions where existing service provision remains inadequate or unreliable[4].

Understanding the performance challenge

Official electrification figures invariably count connections, not quality of provision. Millions of households classified as "electrified" across SSA face unreliable, intermittent and low voltage supply, which means the statistics mask deep shortcomings in system performance and actual energy access. This typically stems from vulnerabilities shared by national grid and mini-grid systems, despite differences in design, ownership and project maturity.

Grid utilities often grapple with load shedding, blackouts, and voltage instability, with transmission losses of 15-30% (versus 8-10% globally[5]) and distribution losses in some countries exceeding 35%[6].

The root causes of these grid vulnerabilities include:

- Ageing infrastructure with inadequate maintenance
- Underinvestment in transmission and distribution networks
- Insufficient generation capacity and weak load forecasting
- Limited regional interconnections that prevent effective load balancing

As a result, rural grid connection rates often remain below 30%, undermining both the financial sustainability of utilities and the expansion of rural electrification projects.

The rapid integration of solar and wind power has further increased system complexity. Without adequate storage, these intermittent resources can exacerbate voltage and frequency fluctuations. Even modern mini-grid systems struggle to balance supply and demand reliably, especially in remote locations. Such technical constraints directly influence tariff levels, payment behaviour, and investor confidence.

Across both grid and mini-grid contexts, the outcome is a vicious cycle: poor service erodes customer trust; distrust depresses revenue; and low revenue constrains reinvestment in improved service.

Whether households, businesses or institutions can fully benefit from electricity access depends on three core attributes:

- **Stability:** The system's ability to maintain continuous service despite fluctuations in supply and demand.
- **Efficiency:** How effectively energy moves from generation through transmission and distribution to end users, minimising losses.
- **Resilience:** The capacity to anticipate, absorb, adapt to, and recover from disruptions, whether from technical faults, extreme weather, cyber-attacks, or demand shifts.

In many rural areas of SSA, these attributes remain weak, and the consequences ripple across sectors. Among other effects, unreliable power undermines healthcare delivery, education, and cold chain integrity. Households cannot depend on lighting or power for study and livelihood activities, while small enterprises face constrained productivity and growth. Many users resort to expensive and polluting diesel generators instead, straining household finances and harming the environment.

iStock, 2021

Emerging solutions and innovation pathways

Regional cooperation offers one route forward. Power pools like the Southern African Power Pool (SAPP) and West African Power Pool (WAPP) enable cross-border energy trade and shared reserves. However, progress depends on harmonised standards, robust interconnectors, and coordinated planning, all of which remain slow to materialise.

More immediate gains are emerging at national and local levels through technological and business model innovation such as:

Infrastructure optimisation:

Cutting-edge energy storage systems maintain reliability amid intermittent supply. Smart grids and data-driven analytics improve load forecasting and infrastructure planning. Drones conduct infrastructure assessments at a fraction of traditional inspection costs, enabling proactive maintenance and preventing failures.

Decentralised assets:

Providing immediate relief to overstretched national networks decentralised systems can also be designed for future grid compatibility, allowing them to serve as transitional infrastructure that supports smoother, more cost-effective grid extension over time.

Demand-side innovation:

Demand-side management (DSM) helps balance loads and reduces reliance on expensive backup or peaking generation. Efficient appliances reduce strain on overtaxed systems.

Participatory systems:

Consumers increasingly act as producers (known as “prosumers”) through trading platforms that enable surplus energy exchange across local and regional grids. This model enhances flexibility and resilience, particularly where traditional infrastructure remains fragile or incomplete.

Enabling environment:

Supportive regulation and innovative financing models prove essential to unlocking scale, attracting investment, and ensuring long-term sustainability.

The report will provide further analysis of many of these innovation areas, showcasing how Energy Catalyst supports solutions that simultaneously improve grid stability and expand meaningful energy access.

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iStock, 2025

Energy Catalyst funding and portfolio analysis


iStock, 2008

Programme overview and strategic focus

Since 2014, Energy Catalyst has invested in more than 300 innovative energy access projects in sub-Saharan Africa, South Asia, and the Indo-Pacific region. Through ten funding rounds, the programme has provided financial and advisory support to entrepreneurs and companies pioneering technologies and business models that accelerate a just and inclusive energy transition, spanning a wide spectrum of energy access solutions.

Over time, innovations related to grid stability, smart grid architectures, load management, energy trading, and hybrid mini-grid systems have become the largest subset of Energy Catalyst's portfolio. The grid-related projects highlighted in this report are drawn primarily from Rounds 7-10 (funded since 2020), a period in which the programme allocated over £110 million to 208 projects across 20 distinct technology areas.

Three priority areas accounted for the majority of this investment in recent funding rounds:

- **Energy storage systems** accounted for the largest allocation with 40 projects, reflecting the pivotal role of batteries and hybrid storage in enhancing reliability, demand management, and grid resilience.
- **Grid and mini-grid solutions** make up a substantial amount of the projects with 29, underscoring their central role in expanding reliable electricity access at scale.
- **New solar technologies** accounted for 20 projects, highlighting a commitment to clean energy innovation capable of delivering affordable, sustainable power.

Together, these allocations reflect Energy Catalyst's strategic focus on strengthening the infrastructure and enabling technologies essential for universal energy access, combining robust grid systems with the generation and storage solutions needed for dependable, high quality service.

Within these three focus areas, 33 projects specifically targeted grid performance challenges, aimed at enhancing stability, resilience, and efficiency across diverse contexts.

Grid performance innovation themes

Projects directly tackling grid performance cluster around five interconnected innovation areas, with many spanning multiple categories:

- Energy efficiency and demand management: Solutions that reduce strain on constrained systems and optimise load profiles.
- Smart grids and analytics: Data-driven tools for real-time monitoring, forecasting, and infrastructure planning.
- Energy storage: Systems that balance supply and demand while integrating intermittent renewables.
- Energy sharing and trading: Platforms enabling peer-to-peer exchange and prosumer participation.
- Decentralised systems supporting grid extension: Modular infrastructure designed for seamless integration with expanding national grids.

These themes highlight how innovators are addressing the persistent barriers of reliability and expansion in emerging markets, particularly in SSA and Asia.

Geographic distribution

The majority of Energy Catalyst's grid performance portfolio is concentrated in SSA, reflecting the region's central role in the global energy access agenda and its acute infrastructure challenges. Beyond Africa, seven projects in Asia and the Pacific address similar grid constraints in contexts ranging from densely populated urban areas to remote island communities.

Figure 2: Map of the number of Energy Catalyst projects per country addressing grid-related challenges[7].

Featured innovations from supported companies

The companies profiled in this report showcase the diversity and practical impact of grid-related innovations supported by Energy Catalyst.

AceOn: Scalable, portable second-life battery systems that enhance grid reliability while reducing reliance on costly diesel backups in Nigeria.

OrxaGrid: A grid analytics platform providing utilities with real-time visibility into distribution network performance, enabling faster fault detection and efficient maintenance in India and Uganda.

Gridimp: Demand-side control technologies that prevent blackouts by intelligently managing load distribution during peak periods in South Africa.

Nanoé: Nano-grids and mesh networks that deliver stable power to rural communities while remaining compatible with future grid expansion in Madagascar.

Ubuntu Energy: A predictive load-sharing platform enabling peer-to-peer electricity trading within micro and mini-grids, improving efficiency and financial sustainability in Nigeria.

Broader development impact

The benefits of these innovations extend well beyond technical performance. By improving grid stability and expanding reliable access, projects supported by Energy Catalyst:

- Boost enterprise productivity and profitability, generating employment opportunities.
- Enhance health and education outcomes by powering clinics and schools.
- Improve household wellbeing through electric lighting, clean cooking, and other domestic uses.
- Strengthen community resilience against economic and climate shocks.

At the same time, these projects demonstrate scalable business models capable of attracting follow-on investment. By generating robust evidence of commercial viability, they provide pathways to accelerate progress toward universal energy access in underserved regions.

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Innovation trends

Energy Catalyst's diverse grid-related portfolio provides a valuable lens through which to understand the evolution of innovation across the energy access ecosystem. The following sections explore key technology innovation trends that are strengthening the stability and efficiency of grid and mini-grid systems.

Each trend has been identified based on compelling evidence of its ability to deliver improved energy access outcomes, while also demonstrating strong potential for job creation and economic growth. The following table provides an overview of each selected trend and its accompanying Energy Catalyst case study, as covered in this report.

This section is not intended as an exhaustive review of all emerging developments in the sector. Rather, it provides an overview of promising grid-related innovations supported by Energy Catalyst across SSA, showing how companies are seeking to translate technological advances into real impact. Some of these case studies cut across more than one trend, reflecting the reality that system-level solutions often integrate diverse technologies to address interconnected challenges.

Trend	Energy Catalyst case study	Geographic focus	Impact
Energy storage for resilience and stability	AceOn	Nigeria, Uganda	Improved grid reliability and reducing reliance on diesel
Data-driven analytics, load management and forecasting	OrxaGrid	India, Uganda	Reduced grid losses, faster fault detection and efficient maintenance
Decentralised energy solutions supporting grid extension	Nanoé	Madagascar	Increased energy access, improved supply
Demand side management, response and appliance efficiency	Gridimp	South Africa	Improved grid resilience, and reduced blackouts
Energy sharing and trading platforms for mini-grid optimisation	Ubuntu Energy	Nigeria	Optimising mini-grid operation, improving efficiency and financial sustainability

Table 1: Summary of trends and case studies

iStock 2025

Trend 1: Energy storage for resilience and stability

Energy storage has become central to modern power systems, simultaneously addressing multiple grid stability challenges and enabling greater integration of renewable energy. Once peripheral, storage has now become essential infrastructure for both national grids and mini-grids.

Mini-grid applications

Within renewable-powered mini-grids, Battery Energy Storage Systems (BESS) are used to balance supply and demand where generation fluctuates with weather conditions. By storing surplus electricity during periods of high renewable output and releasing it during peak demand or low generation, batteries smooth out mismatches between supply and demand. This maximises renewable utilisation and reduces reliance on costly, polluting diesel generators, delivering power at roughly one-third of the cost and with fewer supply chain vulnerabilities[8]. Globally, solar mini-grids already deploy over 1.1 GWh of combined battery capacity, supplying electricity to around 20 million people[9].

National grid applications

Within national grids, BESS mitigate intermittency by buffering fluctuations, allowing solar and wind to operate more like dispatchable resources. They provide frequency and voltage regulation within milliseconds, preventing outages and equipment damage. Batteries also enable peak shaving and load shifting (moving demand from periods of high demand to periods of lower demand), easing transmission stress and deferring costly infrastructure upgrades. Their black start capability (ability to start up independently without relying on the external grid) allows grid components to restart independently after major outages, speeding recovery. For customers on weak grids, batteries reduce or eliminate the need for diesel backup. In some cases, distributed storage can substitute for large-scale grid expansion in remote regions.

Market momentum and projected growth

Battery deployment is expanding at an unprecedented pace. In 2023, the global power sector storage capacity more than doubled. The International Energy Agency projects a sixfold increase by 2030, with cumulative investment reaching USD 800 billion by the end of the decade[10].

The African continent is expected to see some of the strongest growth. Stationary battery capacity is forecast to rise from 11 GWh in 2020 to 83 GWh in 2030, an annual growth rate of 22%[11]. Cost declines and advances in lithium-ion, solid-state, and flow batteries are accelerating adoption. Reflecting this momentum, Energy Catalyst has made battery storage one of its most funded technology areas, supporting innovators such as AceOn, StorTera, JCM Power, and RFC Power.

Outstanding challenges

Despite rapid progress, significant barriers remain:

- Regulatory uncertainty and weak compensation mechanisms for ancillary services continue to undermine the business case for utility-scale batteries.
- End-of-life management is a growing concern. Without proper systems, hazardous waste from spent lithium-ion cells could pose environmental and health risks. While lead-acid batteries benefit from established recycling pathways, lithium-ion recycling remains costly, complex, and safety-intensive.
- Raw material sourcing raises environmental and social issues, from mining impacts to supply chain ethics, underscoring the importance of sustainable sourcing and circular economy strategies.

Addressing these challenges will be critical to unlocking the wider system benefits of storage, enabling other innovations, from smart grids to demand management, to deliver their full impact.


iStock 2025

AceOn, 2024

Case study: **AceOn's flexible battery systems for African grids**

AceOn, a UK-based battery technology company, exemplifies how battery storage can be deployed flexibly to support communities in weak grid settings. Based in Coventry and Telford, with around 30 employees, AceOn has more than 30 years of experience designing and manufacturing custom BESS from portable units to utility-scale installations. It operates a debt free business model combining commercial growth with a strong social enterprise ethos, positioning itself to scale impact in the UK and across Nigeria and SSA.

With support from Energy Catalyst, AceOn has advanced its HIGHESS (High-Capacity Flexible Energy Storage System) project, developing portable, scalable battery systems tailored for underserved regions with unreliable or absent grid infrastructure.

Technical design and deployment model

The HIGHESS system uses second-life lithium iron phosphate (LFP) battery modules repurposed from electric vehicles and buses, with first-life options where appropriate. A pilot trailer configuration delivers 100 kW power output and 215 kWh storage capacity (sufficient to supply 800 people with power for lighting, phone charging and TV for around 65 hours), with scalability through multiple parallel units. Its modular, mobile design enables flexible deployment across rural and humanitarian settings.

AceOn will pilot the system with the Nigerian Red Cross, reducing outages and supporting humanitarian operations while validating real-world performance. The company collaborates with partners including

In2Tec (e-waste reduction), the University of Liverpool (communications systems), and Nevadic in Nigeria.

AceOn's commercial applications

AceOn's BESS systems are designed to meet a wide range of energy and commercial needs:

- Renewable integration: Capturing excess solar or wind generation for later use, reducing diesel reliance and grid imports.
- Energy arbitrage: Leveraging time-of-use pricing with tariff-responsive controls to lower energy bills.
- Solar expansion: DC-coupled configurations that bypass grid constraints, using string optimisers and matched inverters for stable output.
- Behind-the-meter applications: Direct integration with on-site loads for backup and cost-saving benefits.

The company is also exploring new frontiers, including hydrogen fuel cells, advanced battery management systems (BMS), and swappable battery solutions for mopeds and small-scale transport.

Market expansion

Its long-term strategy includes developing a home market in the UK alongside overseas deployment, with a focus on social enterprise and local partnerships. It is expanding its energy storage team and has opened a new operation with offices and unit near Coventry, bringing it closer to the UK Battery Industrialisation Centre (UKBIC) for deeper engagement with the UK's battery sector.

The company's first overseas project on developing sodium-ion battery technology was supported by Energy Catalyst under Round 8, enabling the introduction of new storage technologies to emerging markets.

While designed primarily for African grids and mini-grids, AceOn is also testing applications for its mobile trailer in the UK, such as temporary power for construction sites, festivals, and remote telecommunications infrastructure, with a prototype already piloted in Wales.

Its mobile energy trailers are currently manufactured in the UK, with plans for local assembly in African countries to support job creation and strengthen regional supply chains. In August 2025, with Energy Catalyst Round 10 support, AceOn opened its first international office in Uganda, marking a strategic step toward establishing a broader presence across Africa.

OrxaGrid 2022

Trend 2: Data-driven analytics, load management and forecasting

As energy systems accommodate decentralisation, renewable integration, and growing demand, both national grids and mini-grids face mounting pressure to deliver reliable, affordable, and scalable electricity. Data analytics and smart energy planning have emerged as essential tools for navigating this complexity in infrastructure design, financial sustainability, and operational resilience alike.

Grid operators face interconnected challenges that analytics can address:

Operational reliability: Grids suffer from inadequate maintenance and monitoring, while ageing infrastructure struggles to accommodate decentralised generation. Real-time data from sensors and smart meters enables predictive maintenance, fault detection, and asset health monitoring, reducing outages and technical losses.

Demand forecasting and load management: Mini-grids in rural communities contend with unpredictable consumption patterns, while national grids manage rising demand alongside variable renewable generation. Advanced analytics enable accurate projections, allowing operators to tailor infrastructure, balance loads dynamically, and defer costly expansions.

Financial viability: Limited user ability to pay threatens mini-grid sustainability and grid extension. High aggregate technical and commercial (AT&C) losses and weak cost recovery further undermine utilities' ability to invest in and adopt smart grid solutions.

Combining consumption data with financial modelling helps planners design inclusive tariff structures, identify subsidy needs, and align pricing with local purchasing power.

Investment barriers: Mini-grids often involve small-scale projects with uncertain returns; national grid upgrades require substantial capital. Analytics provide performance benchmarks, risk assessments, and financial projections that de-risk investments and attract private capital, vital for scaling renewable energy and storage.

Grid integration planning: Mini-grid developers face potential asset stranding when national grids expand into their service areas, while utilities must plan for seamless integration of decentralised systems. Data-driven scenario planning helps anticipate grid arrival, inform compensation mechanisms, and guide technical interconnection strategies.

Cybersecurity resilience: As digitisation accelerates through Internet of Things (IoT) devices and smart technologies, new vulnerabilities emerge. Analytics combined with advanced monitoring improve threat detection and enhance grid security.

Energy Catalyst has prioritised smart grid solutions as a key funding area, including support for cohort company OrxaGrid, profiled below.

OrxaGrid

Case study: **OrxaGrid's platform provides real time grid visibility**

OrxaGrid, a UK and India-based technology company founded in 2018, addresses a critical gap in electricity distribution network monitoring. The company identified that distribution networks, particularly in emerging markets, were overwhelmed by inefficiencies and frequent outages due to the absence of real-time visibility. Significant energy was being lost because utilities lacked tools to diagnose causes or intervene effectively.

Technical design and deployment model

OrxaGrid's solution deploys custom-built patented sensors at critical infrastructure points to collect three types of granular data:

- Analogue measurements: Current, voltage, power factor, reactive power
- Digital status indicators: Fault status, on/off power states
- Asset health metrics: Transformer oil levels, temperature

Data transmits to a cloud-hosted platform where proprietary algorithms clean and analyse it, generating actionable insights. Grid operators access dashboards with proactive alerts, enabling faster fault response, intelligent load shedding, enhanced planning, and loss reduction. The modular sensors and customisable dashboards allow each utility to tailor the system to its own operational needs.

Implementation and impact in India

With hardware manufactured by Indian partners and software developed in the UK, OrxaGrid gained rapid traction. The company now serves over six utilities across India, supported initially by Energy Catalyst Round 5 funding. In regions where utilities deployed OrxaGrid's technology and acted on insights, grid losses dropped from approximately 30-40% to around 10-15%. Utilities gained real-time network visibility enabling faster fault resolution and more efficient power delivery, while consumers experienced fewer outages, more reliable service, and lower electricity costs.

Expansion to East Africa

Recognising similar challenges in East Africa, OrxaGrid is designing a pilot project in Uganda's Kasese region with Energy Catalyst Round 10 support. Partnering with UEDCL, the national distribution company, OrxaGrid mapped the network and identified losses approaching 40%. The distributor previously relied on manual tracking, with outages often first reported by customers, which eroded trust and satisfaction.

The pilot is installing sensors at key transformer points to introduce real-time monitoring and predictive alerts, while managing load shedding capabilities. When voltage levels spike, the system calculates permissible transformer loading and automatically disconnects non-essential customers to localise outages. Success will validate OrxaGrid's model for broader deployment across Uganda and neighbouring countries.

Uganda's grid landscape presented distinct challenges compared to India's centralised utilities, including many smaller regional operators in hard-to-reach areas. The hardware also had to be more robust, capable of staying operational across 7-10 year lifespans in remote locations with limited maintenance access. Recent policy shifts nationalising grid ownership under UEDCL simplified deployment but required new certifications for cybersecurity and data protection, which OrxaGrid is actively pursuing.

Business model and growth strategy

OrxaGrid offers flexible commercial arrangements: utilities can choose pay-as-a-service models or one-time deployment fees with ongoing maintenance and customisation. The company funds ongoing development through revenue from existing deployments, supplemented previously by grants and convertible notes from UK investors. Its open-sourced algorithms, refined in collaboration with UK universities, continue evolving, and can detect energy theft.

User feedback drives continuous improvement. Each utility presents unique requirements for digital input/output channels, dashboard preferences, and operational priorities. OrxaGrid responds with modular hardware and widget-based software enabling rapid customisation.

Over the next two years, OrxaGrid aims to expand its Indian footprint while scaling across East Africa. Energy Catalyst-supported outreach in Ethiopia and Somalia has generated pilot interest. Scaling across Africa will require building trust with government utilities, securing pilot funding, and demonstrating the transformative impact of real-time grid visibility through validated performance improvements.

Nanoé 2023

Trend 3: Decentralised energy solutions supporting grid extension

In regions unserved by traditional infrastructure, a critical gap exists between full grid connection and complete off-grid solutions. Decentralised renewable energy systems, including solar home systems (SHS), nano-grids, mesh-grids, and mini-grids, provide pragmatic, scalable bridges across this divide. These systems deliver immediate energy access while laying the groundwork for future grid expansion, enabling phased integration into larger electricity networks.

Far from being temporary stopgaps, decentralised systems are increasingly recognised as strategic infrastructure. Their modularity and flexibility make them especially valuable in remote and underserved areas where extending the grid is financially or technically unviable. As highlighted by the World Bank's ESMAP programme and practical experiences in Nigeria[12], such systems provide reliable power today while maintaining compatibility with future grid upgrades.

The progressive electrification model

Solar Home Systems (SHS) serve individual households with basic lighting and phone charging, an entry point for energy access that can later connect to larger systems.

Nano-grids typically serve four to six households using DC architecture. These self-sufficient units combine solar generation, storage, and backup capabilities, simplifying renewable integration. They operate independently or interconnect to form larger mesh-grids or link to mini-grids. By enabling energy sharing between homes and reducing the complexity of managing distributed systems, nano-grids serve as foundational building blocks for broader grid development.

Mesh-grids cluster multiple nano-grids (typically 10-25 units) into managed networks that enable energy sharing, support communal loads, and provide higher service tiers. Operating on common bus bars with dynamic voltage management, mesh-grids reduce individual system complexity while improving overall utilisation.

Mini-grids can serve hundreds or thousands of customers, often using AC architecture compatible with national grid standards. Modern mini-grids incorporate solar PV with battery storage, smart metres, and remote management systems. Built to be "grid-ready", they enable seamless future interconnection while offering resilience in remote areas. They also support productive uses, such as agricultural operations, cold storage, small manufacturing, that improve load factors and financial sustainability.

This progression reflects the historical evolution of many national grids, which began as interconnected local networks. Current designs deliberately build on this precedent, with advanced controls and interoperability enabling smoother future integration

Requirements for grid compatibility

For decentralised systems to interconnect seamlessly with national grids, several design features are essential, such as island mode operation, interoperability standards and smart technologies. These include IoT platforms, load control systems and energy-efficient appliances, all of which enhance system performance and compatibility. Quality assurance mechanisms like testing, certification, and standards can reduce investment risk and improve bankability, building investor confidence. In addition to the technical aspects, enabling policies need to be in place to really allow scaling and integration of decentralised systems.

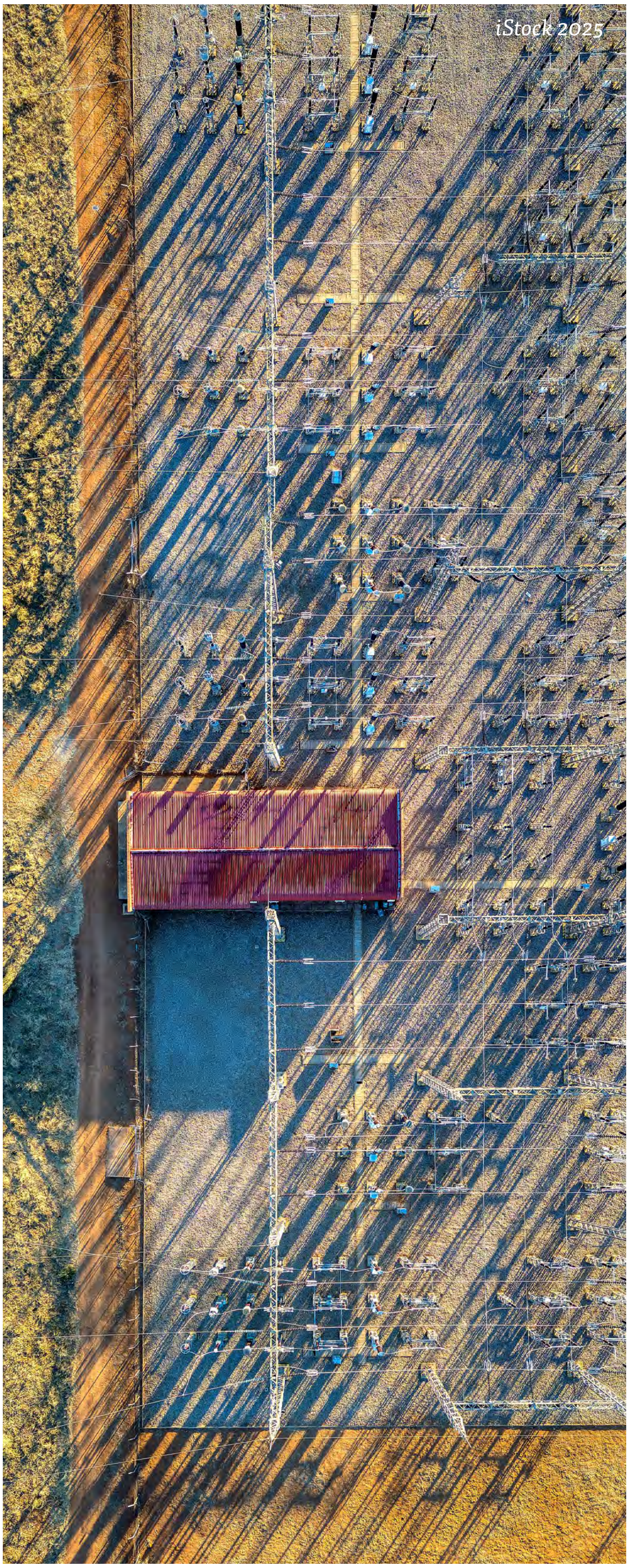
Economic and development benefits

Decentralised systems offer clear advantages over waiting for grid extension, which is why Energy Catalyst has prioritised supporting innovation in this sector (see the 2024 Energy Catalyst report Tackling Challenges in Mini-grid Development).

Key benefits include:

- Accelerated access: Communities gain electricity years before national grid arrival, advancing education, healthcare, and economic opportunities.
- Employment and skills: Installation, operation, and maintenance create local jobs and build technical expertise transferable to larger energy systems.
- Productive uses: Early energy access enables agro-processing, cold storage, and small manufacturing, improving system economics while generating income and employment.
- Scalability and flexibility: Modular deployment reduces upfront capital requirements and allows systems to scale with demand, avoiding the financial risks of oversized installations.

However, mini-grid developers face potential asset stranding when national grids expand into their service areas. Without clear regulatory frameworks on compensation or integration pathways, this uncertainty constrains investment in otherwise viable projects. Some regulators are beginning to address this, with Nigeria's NERC mini-grid regulations including compensation on grid arrival and Kenya's draft mini-grid framework outlining similar provisions.


iStock 2025


Nanoé, 2025

Case study:

Nanoé's scaleable lateral electrification system

Founded in 2017, Nanoé offers a compelling example of a decentralised energy solution serving communities absent of reliable grid power. The company operates in Madagascar with an innovative bottom-up model called "lateral electrification". The approach begins with nano-grids serving small household clusters, scales into mesh-grids supporting communal and productive loads, and ultimately envisions integration with national AC grids. This tiered progression provides immediate energy access while building a pathway toward long-term grid compatibility, offering a replicable approach for underserved regions across SSA.

Technical design and deployment model

Each nano-grid serves four to six households with DC power from solar PV and battery storage, with a minimum of three households required for installation. Customers pay daily via mobile money or field agents (USD $0.16–2.40 per day, depending on available energy and power), with no upfront cost. Flexible service tiers range from 10W for basic lighting and phone charging to 125W for small appliances, allowing households to upgrade as needs and budgets grow.

As clusters expand, mesh-grids link 10–25 nano-grids through a 72V shared bus system. This architecture enables:

- Communal loads such as water pumping, health centres, and schools
- Productive uses including hair salons, agro-processing, multimedia venues and cold storage
- Load balancing and more reliable power supply across connected households
- Higher service tiers with improved power quality and capacity

Nanoé has reached over 12,000 customers across 3,000 nano-grids in 600 villages in northern Madagascar. Four mesh-grids are already operational, with two more planned under Energy Catalyst Round 10 funding.

Commercial model and financial sustainability

Nano-grids typically recover costs within two to four years with an installation cost at around €150 per end-user, competitive with solar home systems but with greater service potential. Daily payments align with household cash flows, while mobile money reduces collection costs and improves convenience.

Funding to date has come from the French government[13], USAID, the EU, and Madagascar-based investors. However, the working capital challenge remains acute: the dispersed customer base and small per-user revenues constrain cash flow. Nanoé is now exploring equity and loan-based financing to support scale.

Local capacity building and social impact

Nanoé employs 90 staff, predominantly Malagasy, and works with a network of 150 trained local entrepreneurs. These entrepreneurs identify customers, manage payments, provide first-line technical support, and share in revenues (20% of collections). The company's role ensures stronger community relationships, reliable fee collection, and rapid troubleshooting in remote areas.

Three-month training programmes equip entrepreneurs with skills in installation, maintenance, and customer service, creating a pipeline of technicians with transferable expertise for Madagascar's broader renewable energy sector. For communities previously reliant on kerosene, the shift to reliable electricity has been transformational, improving living standards and enabling new income-generating activities.

Growth strategy and policy engagement

Nanoé is looking towards piloting interconnection with nearby AC mini-grids in the next few years and exploring eventual integration with the national grid. However, mesh-grid regulations remain undefined in Madagascar, creating uncertainty for investors and operators. By sharing field experience with the energy ministry and regional development banks, Nanoé is contributing to policy development aimed at formalising progressive electrification models.

With Energy Catalyst support, Nanoé has advanced from deploying nano-grids to piloting mesh-grids and building a foundation for eventual grid integration. Its approach demonstrates how modular, affordable systems can expand access step by step - supporting household needs, enabling productive uses, and creating local jobs - while maintaining long-term grid compatibility.

iStock, 2023

Trend 4: Demand side management, response and appliance efficiency

Demand-side management (DSM), demand side response (DSR) and energy-efficient appliances are critical enablers of grid stability and resilience, particularly as electricity systems adapt to decentralised generation and variable renewable energy.

DSM, DSR and efficiency in action

DSM/DSR refers to the strategic modulation of consumer demand through behavioural incentives, time-of-use tariffs, and automated controls. By shifting or reducing peak loads, DSM/DSR reduces stress on generation and transmission infrastructure, lowers reliance on expensive peaking plants, and minimises the risk of outages.

Energy-efficient appliances complement DSM by reducing baseline consumption across households, businesses, and industries. High-efficiency lighting, refrigeration, heating, ventilation and air conditioning (HVAC) systems, and agro-processing machinery lower aggregate demand, flatten load curves, and ease operational planning for utilities. In mini-grids, efficient appliances reduce the generation capacity required, while in larger systems they improve resilience against supply fluctuations, particularly important in grids with high shares of solar and wind. Efficiency also extends the lifespan of grid assets by preventing overload conditions.

Together, DSM and efficient appliances create a more flexible and responsive grid. Smart appliances integrated with pricing signals or demand-response programmes can automatically adjust consumption in real time, aligning demand with renewable generation and acting as a balancing resource during contingencies.

Benefits for emerging markets

In emerging markets, where extending national grids is costly and reliability often uncertain, DSM and efficiency measures provide near-term stability and affordability gains. For rural mini-grids in SSA, where electricity costs remain high, every watt saved translates into lower tariffs and improved system resilience.

At scale, efficiency measures defer infrastructure upgrades, reduce transmission losses, and support a transition from supply-centric planning to demand-aware grid management. This not only strengthens decarbonisation pathways but also empowers consumers to act as active participants in the energy system.

Energy Catalyst is supporting this trend through investment in low-energy inclusive appliances and smart grid innovation, illustrated by the example of Gridimp below.

iStock, 2025

Case study:

Gridimp's intelligent demand-side response for resilient energy systems

With its ability to anticipate grid stress, coordinate distributed resources, and integrate renewable energy, Gridimp is demonstrating how intelligent DSR can become a cornerstone of flexible, inclusive, and low-carbon electricity systems in both emerging markets and advanced economies.

Founded in 2018, the company began by focusing on HVAC load shifting in the UK and has since expanded its platform to manage battery storage, HVAC systems, and electric vehicles, while also integrating solar generation forecasting and dynamic pricing to handle site trading dynamics. The result is a versatile control solution capable of orchestrating multiple energy vectors in real time.

Technical design and deployment model

With Energy Catalyst support, Gridimp partnered with GreenSun in South Africa to address national public utility Eskom's chronic load shedding, which disrupts economic activity and places heavy strain on municipal finances. In Hessequa municipality, for example, outages were costing as much as 3 million rand (USD 175,000) per month.

The project deployed solar-plus-storage systems integrated with Gridimp's automated demand-side controls, directly linked to Eskom notifications to anticipate load-shedding events. The system uses IoT sensors, new software modules, and customised interfaces for microgrid controllers to manage battery charging and discharging in response to real-time conditions.

Key features include:

- Forecasting generation and demand every 30 minutes to optimise system performance
- Adaptive control that responds dynamically to pricing signals and weather patterns
- Hybrid cloud and on-site architecture ensuring resilience even when network connectivity is lost

This configuration enables batteries to be pre-charged before load-shedding events and demand to be minimised during peak price periods, significantly improving system resilience.

Implementation and results

Trial deployments proved highly effective. Batteries were consistently charged in advance of outages, municipalities avoided financial losses, and peak demand was substantially reduced. Customers, both commercial and residential, subscribe to the platform through a service model that runs autonomously, requiring minimal manual intervention.

Building on these results, Gridimp and GreenSun are now developing a commercial municipal-scale model, including a planned 10 MW PV-battery installation with the potential to supply township households via wheeling arrangements (agreements to use third party distribution and transmission networks). This demonstrates the scalability of the platform beyond pilot contexts and its ability to support inclusive energy provision at the community level.

Positioning in the UK market

Alongside its international work, Gridimp is also positioned at the forefront of the UK's fast-evolving flexibility market. National policy drivers, such as half-hourly settlement and the Smart Secure Energy System programme, are creating new opportunities for flexibility services. Looking ahead, UK energy scenarios project a need for 40 GW of flexibility to balance intermittent renewables and electrified heating.

In this context, Gridimp's platform provides commercial and institutional customers - including factories, universities, and office complexes - with the ability to optimise energy use, integrate on-site renewables, and reduce costs while contributing to grid decarbonisation.

Growth strategy and future outlook

Gridimp's immediate priorities include refining its commercial model, tailoring the platform for diverse operating conditions, and securing investment to support expansion. By building partnerships with energy service companies (ESCOs), the company aims to scale deployments that deliver both cost savings for consumers and system-wide resilience benefits.


Nanoé, 2023

Trend 5: Energy sharing and trading platforms for mini-grid optimisation

Energy sharing and trading platforms are transforming the way distributed energy systems operate by enabling dynamic power flows between users, systems, and communities. These platforms move mini-grids beyond isolated operation, optimising how locally generated electricity is consumed and shared to strengthen efficiency, resilience, and financial sustainability.

Peer-to-peer energy trading

A central innovation in this space is peer-to-peer (P2P) energy trading. Households or businesses with surplus energy, whether from solar PV or battery storage, can sell or share it with others in their network. This approach:

- Improves system utilisation by ensuring excess generation is not wasted
- Incentivises prosumers to invest in renewable generation and storage
- Reduces reliance on diesel backup or oversized systems
- Balances loads across users, lowering costs and enhancing reliability

For mini-grids, P2P trading increases revenues for both operators and participants by aligning local supply with demand in real time.

Digital enablers

These innovations rely on smart metering and IoT-enabled platforms that monitor consumption, generation, and grid health in real time. Key functionalities include:

- Dynamic pricing to reward flexible consumption and incentivise trading
- Remote diagnostics and predictive maintenance to reduce downtime
- Load control and distributed resource integration to optimise system performance

In mini-grid contexts, where user profiles and renewable generation vary widely, such platforms are critical for scaling energy sharing and maintaining reliability.

System-level impact

By enabling energy to flow where it's most needed, energy trading platforms can significantly enhance the efficiency of nano-, mesh- and mini-grids. They can deliver a range of benefits at the network level:

- Better utilisation of batteries and solar PV assets
- Reduced dependence on costly backup systems
- Diversified revenue streams that improve financial sustainability
- Greater resilience against demand fluctuations and seasonal variability
- Support for more inclusive, community-level energy planning

Policy and regulatory enablers

Technology alone cannot ensure success. Supportive policy and market frameworks are vital for scaling these models. Key enablers include:

- Recognising prosumers and energy traders as formal market participants
- Establishing tariff structures that reflect local generation and trading dynamics
- Ensuring hardware-software interoperability through open standards
- Piloting models through regulatory sandboxes and test programmes

Countries such as Nigeria and Kenya are already experimenting with these approaches[14], providing valuable lessons for broader market adoption.

Energy Catalyst is supporting multiple digital platforms that enable consumer participation, including Ubuntu Energy, profiled below.


iStock 2021

Case study:

Ubuntu Energy's predictive load sharing platform

Founded in 2024 as a UK-registered subsidiary of Greenage Technologies, Ubuntu Energy tackles one of Nigeria's most pressing energy paradoxes: the coexistence of abundant idle solar capacity and severe energy scarcity. Across the country, large PV systems, installed at schools, business plazas, or affluent homes, often operate below capacity, even as nearby communities remain underserved and dependent on expensive diesel generators.

Ubuntu Energy has developed a predictive load-sharing platform that enables communities to buy and sell electricity within micro- and mini-grids, unlocking underutilised solar generation and transforming it into a shared community resource.

Technical design and deployment model

Ubuntu Energy's platform integrates real-time monitoring, predictive analytics, and smart trading software to redistribute energy dynamically:

- Data collection and analysis: The system gathers load profiles, generation forecasts, and consumer usage patterns through non-intrusive load monitoring. Using Solar Geographical Information System (GIS) data and advanced modelling, the platform predicts available capacity and demand trends.
- Matching supply and demand: Idle solar capacity from sites such as school rooftops or seasonally occupied large homes (from 1kW to 50 kW PV systems) is matched with nearby energy-deficit consumers.

- Metering and distribution: Power is metered centrally at anchor producer sites (e.g. business plazas) and distributed to end-users via a low voltage AC grid with radio-linked sub-meters, minimising costs, preventing bypass and reducing theft.
- Optimised dispatch: Predictive load forecasting informs optimal timing and capacity allocation across devices, ensuring that energy is dispatched where and when it is most needed.

Initial deployments focus on localised smart grids within 50 metres of anchor loads, with expansion to 100 metres underway, avoiding the high costs of new high-voltage infrastructure.

Commercial model and user engagement

Ubuntu Energy's business model creates value for both producers and consumers:

- Producers: Solar asset owners earn revenue by selling surplus energy, incentivising investment in PV systems and storage.
- Consumers: Pay $0.30–0.50/kWh, significantly lower than diesel generation (around $1/kWh). Payments are made monthly in advance via mobile apps or SMS, with options for daily billing under development to improve affordability for low-income users.
- User experience: Consumers monitor usage via SMS or apps and receive advance notifications for high-load appliance availability. During onboarding, users register their appliances, enabling day-ahead guidance on energy use, with plans to extend to weekly forecasting. This shifts households from passive consumption to active energy management.
- Revenue sharing: Producers retain 40% of traded energy revenue, installation partners receive 20%, and Ubuntu Energy retains 40%. Partners' usage-based earnings incentivise both installations and customer engagement.

Implementation and expansion strategy

To date, Ubuntu Energy has deployed 20 systems, which are fully integrated with the trading platform and aims to scale to 200 sites by April 2026. Early deployments demonstrate the model's adaptability across rural and urban contexts:

- Enugu State: Rooftop solar sharing reduces dependence on diesel generators, cutting noise and emissions in dense urban communities.
- Kano State: Smart grid integration trials with grid operators explore virtual power sharing across solar home systems and mini-grids.

Ubuntu Energy navigates Nigeria's fragmented regulatory environment through Memorandums of Understanding with the Rural Electrification Agency and state governments. By mapping installed PV capacity and layering predictive load maps, the company develops roadmaps for inclusive electrification tailored to local contexts.

Business model and growth strategy

Ubuntu Energy designs its systems at a new factory in Nigeria, sourcing semiconductors and transistors internationally. With support from Energy Catalyst Round 10 for technology development and from UNIDO's Accelerate to Demonstrate facility for scale-up, the company is preparing to raise equity for mass deployment across thousands of sites in Nigeria and other markets.

By converting idle capacity into productive supply, Ubuntu Energy's model creates local energy markets that improve affordability, resilience, and sustainability. It demonstrates how predictive trading platforms can optimise distributed networks, reduce reliance on diesel, and extend reliable power to underserved communities.

ENERGY CATALYST

iStock, 2019

Cross-cutting benefits and potential impact

The grid stability and efficiency innovations supported by Energy Catalyst and explored above extend far beyond technical performance improvements. By delivering reliable, affordable electricity, they catalyse progress across multiple Sustainable Development Goals, creating a multiplier effect with the potential to transform communities and economies.

- **Healthcare:** Reliable power is fundamental for cold chain storage of vaccines, diagnostics, and telemedicine. OrxaGrid's grid analytics in Uganda, for instance, will enable utilities to reduce outages and losses, ensuring clinics can operate consistently. In humanitarian contexts, AceOn's battery trailers can provide back-up power at one-third the cost of diesel, safeguarding health services when grids fail.
- **Education and digital inclusion:** Stable electricity extends study hours and allows schools to deploy digital tools. In Nigeria, AceOn's work with the Nigerian Red Cross ensures classrooms and learning centres continue operating during outages. Learning that relies on online access only truly becomes possible with consistent energy supply.
- **Economic productivity:** Reliable mini-grids and trading platforms like Ubuntu Energy's reduce energy costs from around $1/kWh for diesel to $0.30–0.50/kWh for solar-plus-storage. This cost reduction makes agro-processing, cold storage, welding, and small manufacturing commercially viable, improving both business margins and food security.
- **Climate resilience:** Storage-backed mini-grids power irrigation during droughts, reduce food losses during heatwaves, and keep communications online during extreme events. Flexible storage systems such as AceOn's and predictive trading platforms like Ubuntu Energy's create resilience against both climate and economic shocks.
- **Gender equity:** Energy poverty disproportionately affects women, who spend hours collecting biomass or are exposed to indoor air pollution. Reliable electricity reduces these burdens while improving safety through well-lit streets and clinics. At the same time, the energy sector itself remains male-dominated, with women in only a quarter of senior management roles. Ubuntu Energy's local engagement models and Nanoé's community entrepreneur networks provide platforms for women to participate as agents of change, not only as beneficiaries.
- **Local employment and skills development:** New career paths span manufacturing, installation, and maintenance, while training in areas such as solar installation, metering, and data analytics builds transferable technical capacity across the energy sector. For example, AceOn is preparing local assembly lines, Ubuntu Energy has opened a factory in Enugu, and Nanoé employs 90 Malagasy staff alongside 150 community entrepreneurs.

These innovations also reinforce the business case for grid strengthening. By reducing outages, stabilising voltage, and cutting technical losses, electricity suppliers lower operating costs and improve customer satisfaction. Higher payment rates then strengthen revenue streams, creating a virtuous cycle where utilities are incentivised to extend the grid further. For private developers, diversified revenue streams, such as Ubuntu Energy's trading fees or AceOn's arbitrage services, support financial sustainability, while modularity reduces upfront capital risk.

iStock, 2023

Learnings and recommendations

The innovations featured in this report demonstrate how targeted technologies can improve grid stability and efficiency, but they also underline broader programme-level lessons about how these solutions are developed, tested, and scaled.

1

Modularity and scalability are essential

Energy systems must adapt to evolving demand and diverse market conditions. Modular batteries, nano- and mini-grids, and interoperable platforms enable stepwise growth and reduce the risks of oversizing. Testing solutions in different contexts and adapting them to local realities is central to long-term sustainability.

2

Local context and partnerships matter

Successful deployment depends on collaboration with local partners, communities, and institutions. These collaborations ensure that solutions reflect cultural, social, and economic realities, while also building trust and ownership. Through its ecosystem networks, Energy Catalyst enables innovators to work directly with local partners, strengthening relevance, uptake, and long-term capacity.

3

Policy and regulation are lagging behind innovation

Every technology trend highlighted in this report - storage, grid analytics, decentralised electrification, demand-side management, and energy trading - faces regulatory uncertainty. Second-life batteries lack clear safety and recycling standards; decentralised systems such as mesh-grids and peer-to-peer trading lack licensing pathways; and digital tools for grid analytics and demand response raise cybersecurity and data governance issues. More regulatory sandboxes and evidence-based policymaking are needed to create enabling environments where these solutions can scale.

4

Interoperability drives convergence

Scalability depends on interoperability across components, systems, and business models. Open standards, modular hardware, and interoperable software enable technologies to work together and integrate with national grids over time. This convergence - technical, commercial, and digital - amplifies impact by turning isolated innovations into integrated, system-level solutions.

5

Financing, efficiency and sustainability must go hand in hand

Scaling these solutions requires targeted de-risking instruments, such as blended finance, results-based funding, and guarantees, to crowd in private capital. Productive use stimulation strengthens the economics of decentralised grids, while efficiency measures reduce peak demand and extend asset lifespans. Affordability mechanisms, including lifeline blocks, subsidy design, and results-based financing (RBF) targeting, as well as lifeline tariffs, are critical to ensure equitable access while maintaining financial sustainability.

6

Embed environmental safeguarding

Sustainability must be integrated from the outset through ethical sourcing, safe end-of-life management, and circular economy approaches such as reuse and repair. Embedding these safeguards ensures that energy innovations protect ecosystems and communities while delivering reliable, affordable power.


iStock, 2022

Conclusion

The Energy Catalyst programme is driving a new wave of innovation to strengthen the stability, efficiency, and resilience of grids and mini-grids across SSA, as well as in Southeast Asia and the Pacific. More than a source of finance, it acts as a platform for testing, iteration, and deployment in real-world conditions, enabling innovators to validate technologies, refine business models, and prove their impact at scale.

By generating commercial evidence, informing policy dialogue, and sharing lessons across markets, Energy Catalyst accelerates the spread of solutions that are not only technically viable but also socially inclusive and context-specific. Its portfolio approach ensures that insights from one region can be applied in another, while close collaboration with local partners and communities keeps solutions relevant, equitable, and sustainable. From this vantagepoint, the programme is well-positioned to identify broad innovation trends and cross-cutting solutions, helping to shape the future direction of the energy access sector that will be supported by long-term investments.

iStock, 2024

Convergence as the next frontier

One of the strongest lessons emerging is that progress will not depend on isolated breakthroughs but on the convergence of technologies and business models into integrated systems. Several strands of convergence stand out:

- **Technical convergence:** Energy storage, smart metering, digital platforms, and demand-side management are increasingly designed to interoperate. Advances in modular power electronics and IoT monitoring mean systems that once operated independently can now support grid analytics, trading, and predictive maintenance simultaneously, provided that data portability and open standards are adopted to ensure long-term interoperability and avoid vendor lock-in.

- **Business model convergence:** The sector is moving from reliance on unit sales of equipment or kWh to service-based and subscription models. Diversified revenue streams, such as trading fees, demand response services, and productive use support, improve financial sustainability and reduce exposure to risk.

- **Grid integration pathways:** Decentralised systems are being designed for compatibility with national networks from the outset, avoiding stranded assets. Nano- and mesh-grids can expand into mini-grids; mini-grids can link seamlessly into national grids, creating a progressive electrification pathway that delivers immediate services while supporting long-term system integration.

- **Digital convergence:** Digital infrastructure is emerging as the backbone of future systems. Platforms now combine billing, metering, forecasting, performance monitoring, and user engagement, providing operators with tools to scale efficiently and integrate diverse distributed energy resources.

To capitalise on these trends, the sector must plan actively for convergence, ensuring interoperability standards, regulatory frameworks, and financing mechanisms are in place to support integrated, multi-functional systems.

Future trends

Looking forward, several emerging technologies and approaches will increasingly shape the next phase of innovation:

- **Artificial intelligence and machine learning:** Beyond current predictive analytics, AI will enable autonomous orchestration of distributed resources, dynamic pricing based on real-time conditions, and predictive maintenance at scale.
- **Blockchain and distributed ledgers:** Secure, transparent transaction recording will support peer-to-peer trading at scale, support renewable energy certificate verification, and build trust in fragmented markets.
- **Advanced energy storage:** Next-generation technologies, including solid-state and flow batteries, promise greater sustainability, safety, and performance compared with conventional lithium-ion.
- **Digital finance and identity systems:** Integration with mobile money and digital IDs can reduce transaction costs, enable innovative tariff structures, and broaden participation among low-income users.

These innovations are increasingly interdependent, reinforcing the importance of designing systems that are modular, interoperable, and adaptable to diverse contexts.

Pathways to scale

Scaling these solutions requires more than technology development. The pathway involves leveraging demonstrations to refine technical and commercial models, building robust evidence for investors, and informing policy advocacy. At the same time, enabling environments must evolve to support modular, interoperable technologies and equitable market access. This includes frameworks for data governance, flexible tariffs, and participation of decentralised assets in broader markets.

As energy systems grow more complex and climate pressures intensify, ecosystem building becomes increasingly vital. Future sector support is likely to expand beyond enabling individual innovators to embrace convening diverse stakeholders and driving system-wide transformation. Through this role, programmes will be in a stronger position to embed environmental sustainability and social equity as foundational principles of the global energy transition.

Endnotes

[1] IEA 2024: Electricity Access Continues to Improve in 2024 After First Global Setback in Decades

[2] Unless otherwise stated, mini-grids here refers to mini-, mesh-and nano- grids.

[3] ESMAP 2022: Mini-grids for half a billion people, Mini Grids for Half a Billion People:Market Outlook and Handbook

[4] World Bank 2024: Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India (International Development in Focus; B. Tenenbaum, C. Greacen & A. Shrestha)

[5] World Bank 2024: Electric Power Transmission and Distribution Losses (% of output)

[6] Nigerian Electricity Regulation Commission 2024: Annual Report (NERC)

[7] Note this map reflects projects addressing grid related challenges and themes identified in this report and do not reflect all grid and mini-grid projects supported by Energy Catalyst.

[8] Energy Catalyst 2022: The Role of Energy Storage in Achieving SDG7: An Innovation Showcase

[9] IEA 2024: Batteries and Secure Energy Transitions (World Energy Outlook Special Report)

[10] IEA 2024: Batteries and Secure Energy Transitions (World Energy Outlook Special Report)

[11] World Economic Forum 2021: Closing the Loop on Energy Access in Africa

[12] World Bank 2024: Mini Grid Solutions for Underserved Customers: New Insights from Nigeria and India (International Development in Focus; B. Tenenbaum, C. Greacen & A. Shrestha)

[13] Fonds Francais pour L'Environnement Mondial 2025: Un Trajectoire d'Innovation au Service en Vivant.

[14] African Leadership Magazine 2024: The Impact of Africa's Regulatory Sandboxes on Innovation

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