CrossBoundary

Mini-Grid Innovation Lab

Innovation Insight

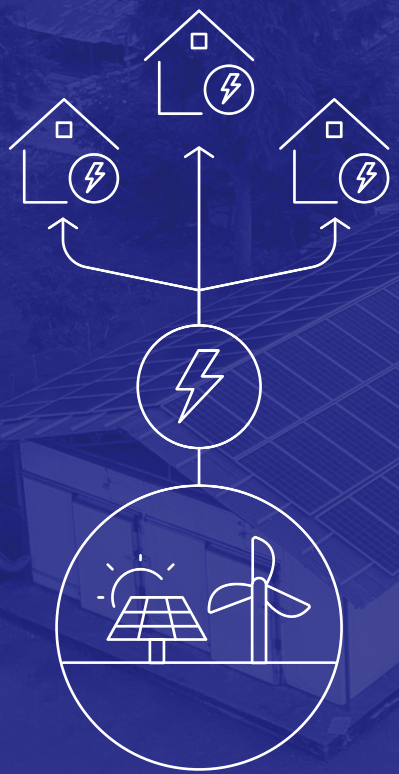
Mesh-grids

A Scalable, Cost-Effective Alternative for Rural Electrification

UK aid from the British people

Transforming Energy Access

May 2025



About the CrossBoundary Mini-Grid Innovation Lab

CrossBoundary's Mini-Grid Innovation Lab, part of CrossBoundary Group, is Africa's first R&D fund exclusively focused on testing new business model innovations for mini-grids, designed to close the gap on the 618 million Africans who do not have power. The Mini-Grid Innovation Lab works with developers across the continent to test innovations to make mini-grids a more reliable and commercially viable solution. For additional information, visit **www.crossboundary.com/labs**.

This study and innovation insight was funded with UK aid from the UK government via the Transforming Energy Access platform.

Funded By:

UK aid from the British people

Transforming Energy Access

This material has been funded by UK aid from the UK government; however the views expressed do not necessarily reflect the UK government's official policies.

Executive summary

Mesh-grids are emerging as a versatile and cost-effective approach to rural electrification and could complement mini-grids in the pursuit of global energy access targets

The Lab, with support from the UK government via the Transforming Energy Access platform, set out to assess the technical and financial viability of mesh-grids in comparison to mini-grid deployments at a similar scale to understand their comparative economics. Results are compared across two different mesh-grids sites in Nigeria; one site with full mesh-grid deployment, and one site where mesh-grids were used to extend access to those at the periphery of the grid. Though results are based on a limited sample and not statistically significant, these results reveal important trends that could help mini-grid developers identify emerging opportunities and alternative deployment models.

Mesh-grids' cost advantage is strongest for full deployment, and operational benefits are highly contingent on developer operating models

- Mesh-grids demonstrate 41% lower capital expenditure (CapEx) per connection for full-site deployment— $803 per connection versus $1,358 per connection at the mini-grid control site, and 23% lower CapEx per connection than more recent regional benchmarks. However, for grid extension at the periphery, mesh-grids can be more expensive— $651 per connection compared to the same $449 per connection cost at the mini-grid control site[1].
- For full-site deployments, mesh-grids incur 95% lower distribution CapEx per connection— $12 per connection versus $247 per connection at the mini-grid control site. For extensions, mesh-grids cost $4 per connection versus $169 per connection for the conventional mini-grid setup[2].

1. Minigrid extension did not require additional PV and battery capacity.
2. Meshgrid distribution costs do not include poles.

- Operational expenditure (OpEx) savings are highly contingent on different developer operating models. At the full-site deployment, yearly OpEx per connection is $28 per connection compared to $3 per connection at the mini-grid control site. At the extension site, mesh-grids cost $7 per connection versus $33 per connection for the mini-grid control site.
- Similarly, ability to deploy mesh-grids connections varies according to developer operations - full-site mesh-grid installations can achieve up to 1.5 times faster deployment at 3 connections per day; but at the extension site, the developer achieved 1 connection per day.

Mesh-grids demonstrate higher reliability than mini-grids and can maintain competitive revenue despite lower consumption per user

- Mesh-grids maintained 99% reliability at the full-site deployment compared to 27% at the mini-grid control site[1]. Similarly at the extension site, mesh-grids maintain 96% reliability versus 60% at the mini-grid equivalent[2].
- The full deployment mesh-grid treatment site recorded 213% higher ARPU than the mini-grid control site while the extension mesh-grid site recorded 25% higher ARPU than the minigrid control site.

Mesh-grids are increasingly proving their potential for rapid deployment at scale in challenging conditions

Mesh-grids are transforming rural energy access in Haiti, powering 4200 households with reliable and affordable energy. A case-study of the Alina Eneji mesh-grid development demonstrates:

- Cost per connection of $545, which is one-third of the $1,627 per connection seen for mini-grids in Haiti
- Fast deployment speeds with peak installations of 30 – 40 households per day, and 98% average system reliability

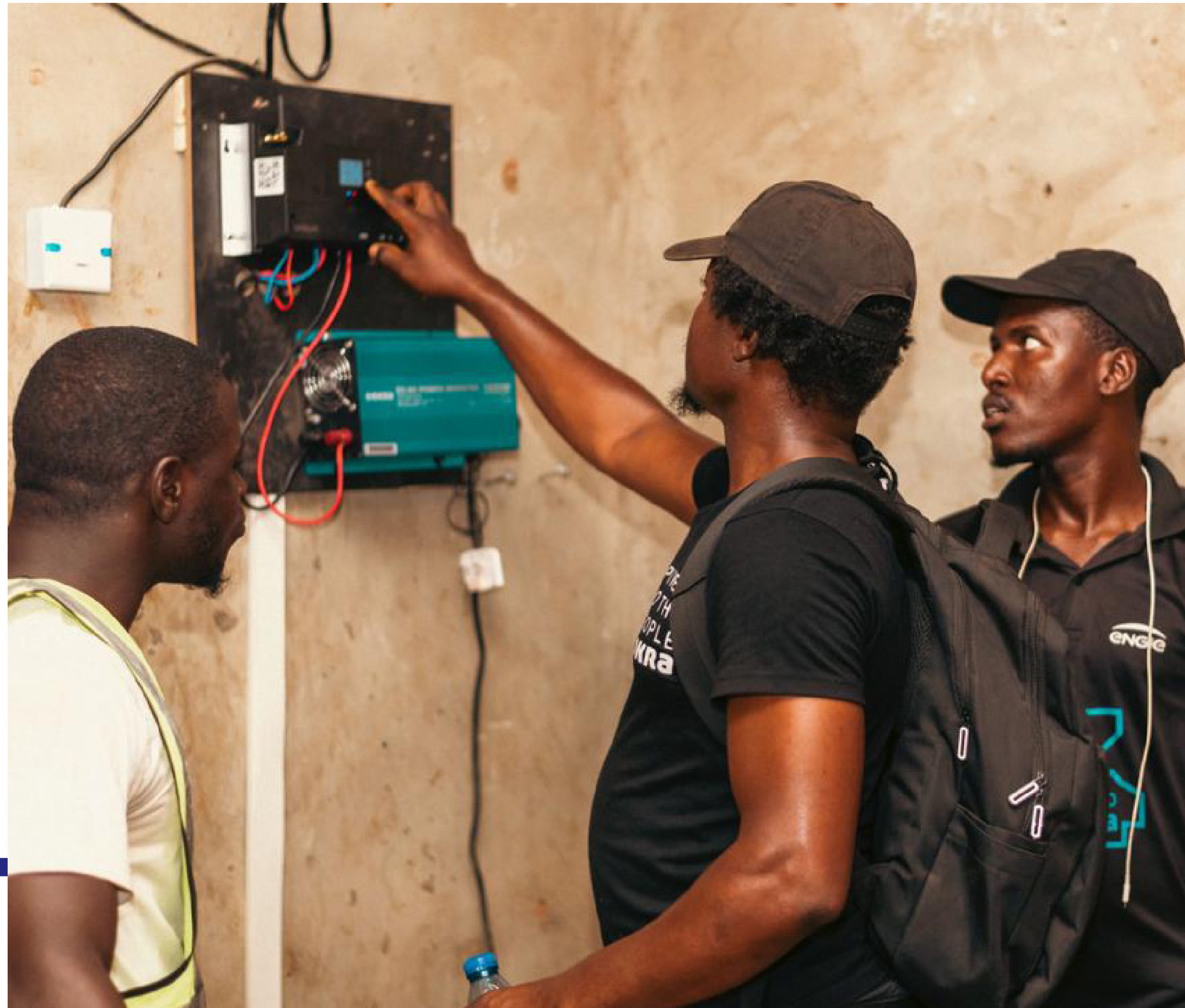
1. The developer reported a reliability of 93% and availability of 100% for the first 6 months after commissioning.
2. The developer reported a reliability of 97% and availability of 100% for the first 6 months after commissioning.

Though mesh-grids are demonstrating high performance, their ability to meet PUE loads and sustain their efficacy in the long term is yet to be determined, which could impact their return on investment (ROI)

- The relatively low power output of mesh-grids, typically around 1.2kW per individual system, limits their ability to serve productive use customers with high energy demands
- The long-term impact of wear and tear on mesh-grid reliability remains uncertain, as large-scale deployments are still relatively new and have only been in operation for a few years

Despite this uncertainty, mesh-grids are emerging as a scalable, cost-effective, and resilient solution for decentralized electrification, particularly in underserved and remote communities

The Innovation Lab will continue gathering data on mesh-grids to address critical questions around their potential for productive use, long-term performance, and cost-effectiveness. Insights from additional suppliers will be key to building a comprehensive understanding of mesh-grid viability. We welcome collaborators to share data and insights to help advance research in this emerging field. To explore partnership opportunities, please contact minigridslabs@crossboundary.com.



About this prototype

Mesh-grids consist of interconnected solar energy kits that can share power

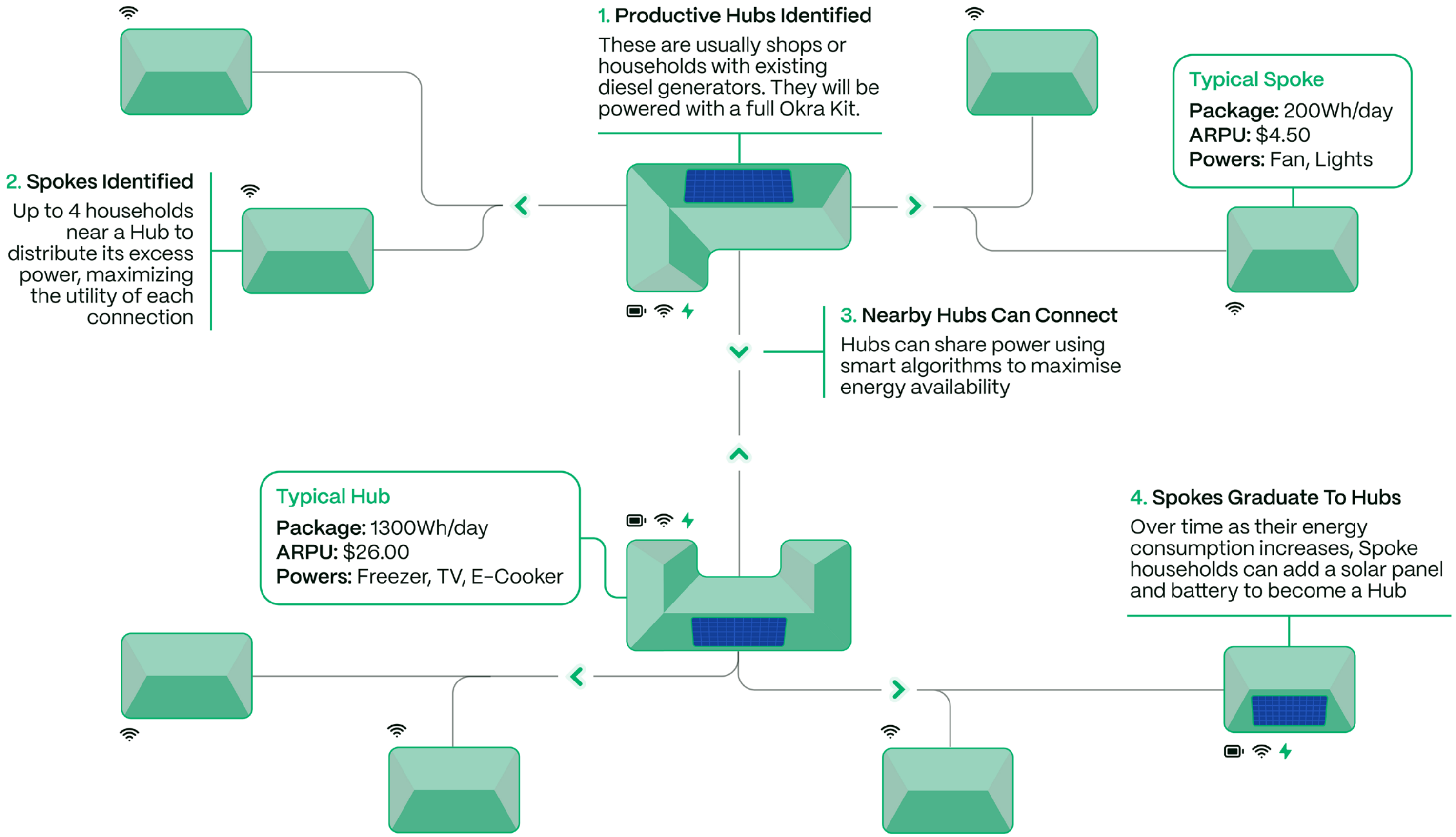
The Lab tested two different configurations of mesh-grids in Nigeria via two different developers: one site with full mesh-grid deployment, and one site where mesh-grids were used to extend access to those at the periphery of the grid.

Data from these sites has been compared to two control sites that belong to the same developers. The control sites are in close proximity to the mesh-grid sites and have similar community profiles. Both control sites are more mature than the mesh-grid sites in terms of operational history.

The Lab has supplemented this with data from a case-study from the Alina Eneji site in Haiti, which is a full deployment across 4200 connections.

Full site deployment mesh-grids site

At one treatment site mesh-grids were deployed across an entire community in a Hub and Spoke network, where one central node (the "Hub") serves as the focal point for energy consumption, while multiple peripheral nodes (the "Spokes") connect directly to the hub and receive surplus energy from it. The surplus energy is typically used for lighting and powering smaller appliances with a demand of less than 1kWh per day. Distribution is 50V DC with 230V AC available at the household level.



Full site

Number of connections: **143**

Date of Commissioning: **12/2024**

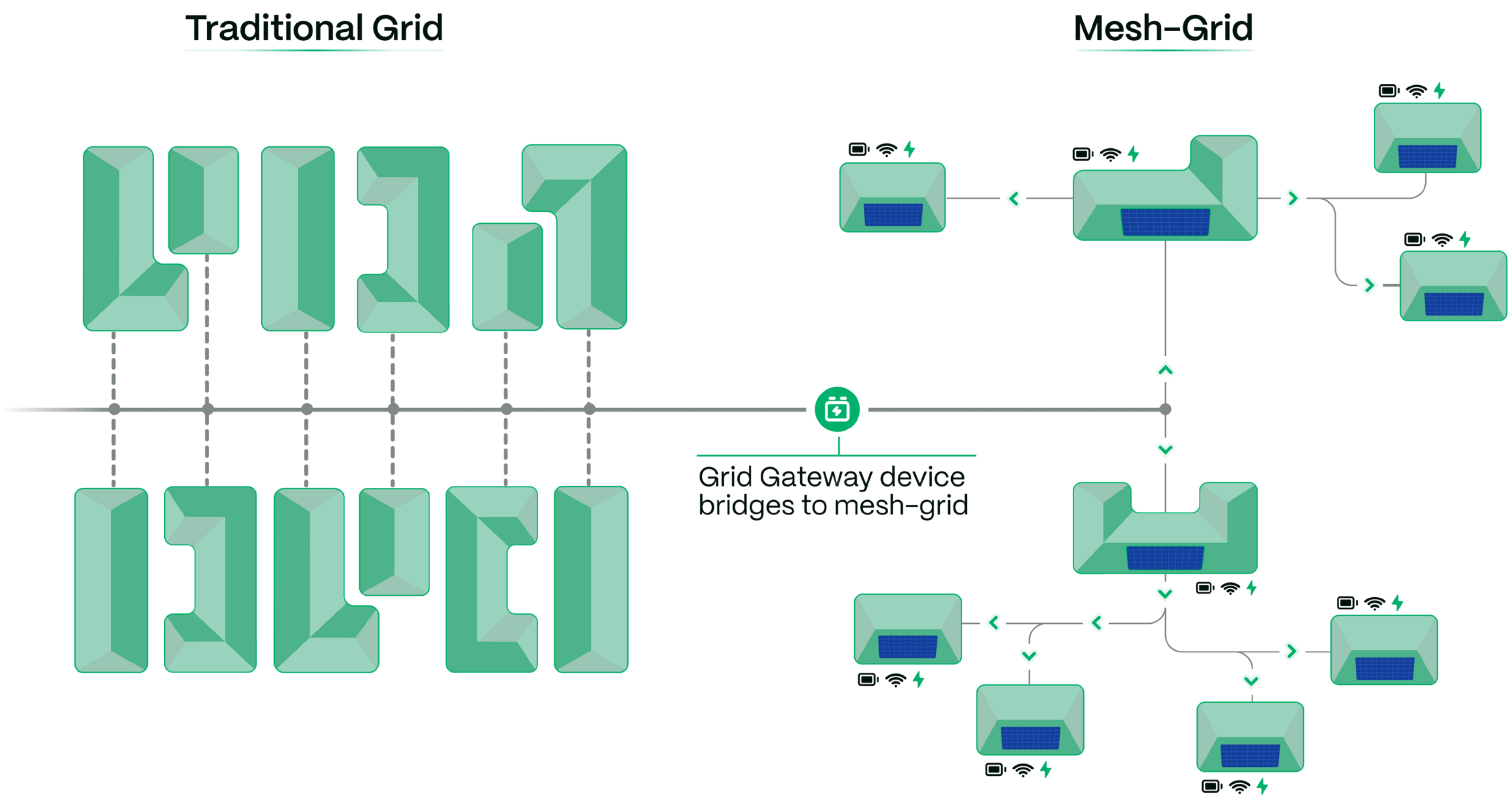
Control site

Number of connections: **343**

Date of Commissioning: **4/2020**

Grid extension mesh-grid site

At the other treatment site, mesh-grids were deployed at a community adjacent to an existing mini-grid, to assess whether this would be a more cost effective and technically viable alternative than extended Medium Voltage (MV) lines to connect that community. The mesh-grids are designed in an 'All-Hub' configuration, with each household having it's own solar panel and battery unit.



Full site

Number of connections: **67**

Date of Commissioning: **3/2023**

Control site

Number of connections: **501**

Date of Commissioning: **12/2021**

01

Mesh-grids cost advantage is strongest for full deployment

Full deployment mesh-grids are 41% cheaper than conventional mini-grids, but extending the grid is cheaper when using conventional approaches

What we're seeing

The full deployment mesh-grid treatment site has a 41% lower CapEx per connection cost at $803 per connection compared to the mini-grid control site at $1358 per connection and was 23% cheaper compared to more recent mini-grid benchmark data from West and Central Africa.

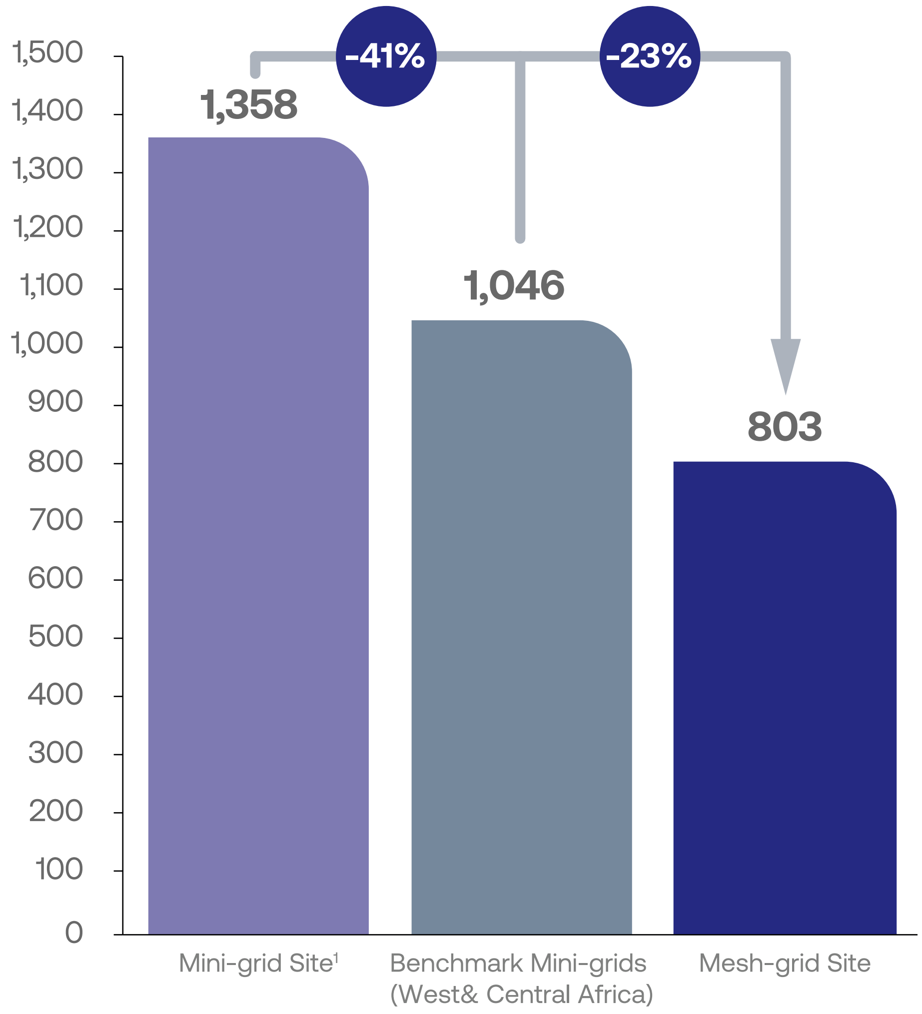
The mesh-grid extension site has a 45% higher CapEx per connection at $747 per connection compared to the mini-grid control site at $449 per connection.

What it means

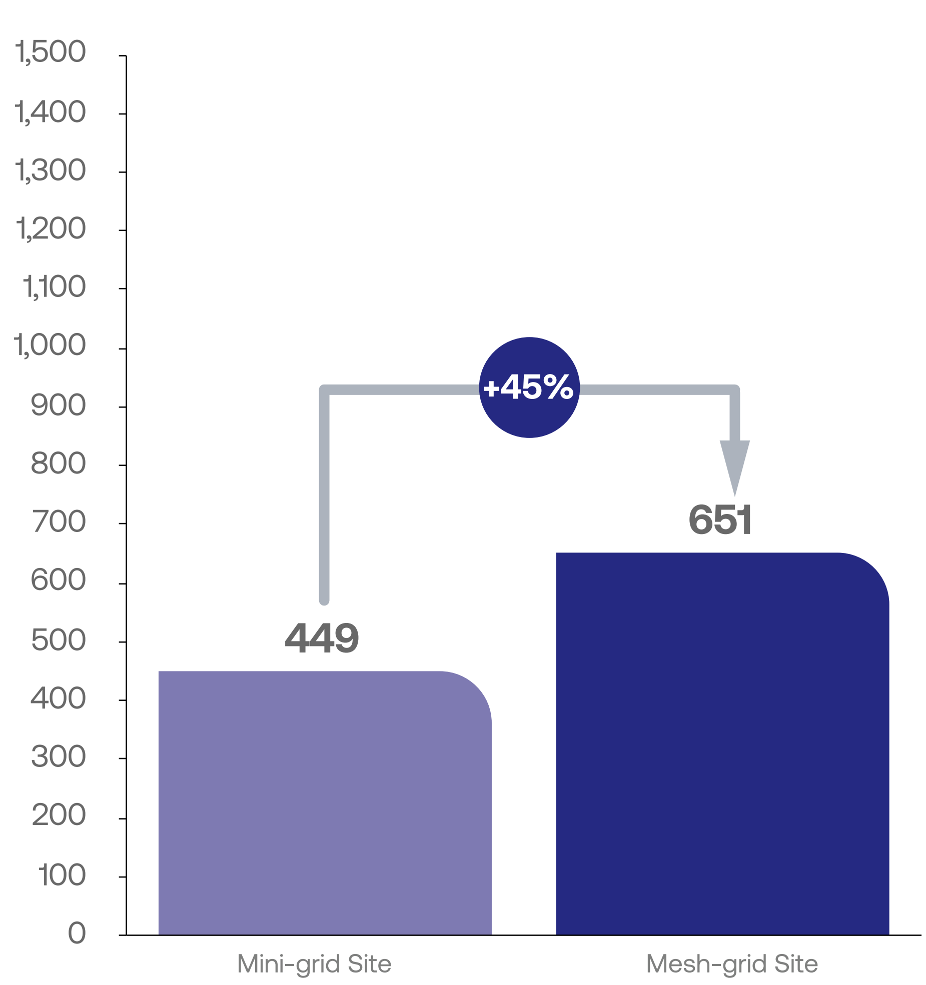
For full deployment sites, mesh-grids are cheaper to deploy than mini-grids. The higher CapEx of the full deployment mini-grid site reflects its age, having been commissioned in 2020. However, this still holds true for more recent benchmarks, indicating cost competitiveness.

At the periphery, however, it may be more economical to extend the existing mini-grid rather than deploying mesh-grids. In this case, lower mini-grid costs stemmed from the fact that only distribution infrastructure was needed, as there was already sufficient PV and storage capacity on-site. That said, this advantage is highly site-specific and may vary depending on the available capacity and distance from the Powerhouse.

CapEx per connection comparison, mesh-grid to mini-grid full deployment site ($)



CapEx per connection comparison, mesh-grid to mini-grid extension site ($)



1. This mini-grid was built to serve a large mining community that has since relocated, leaving far fewer customers than planned and inflating CapEx per connection.
Note: Conventional approaches here are mini-grids with PV solar systems, battery storage and backup diesel generators
Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites
Mini-grid benchmark data: AMDA Benchmarking Africa's Mini-grids Report (2025)

Mesh-grids have lower distribution costs achieved through their simplified DC outlay

What we're seeing

The mesh-grid treatment sites have an average >95% lower distribution CapEx per connection compared to the mini-grid control sites with an average CapEx of $8 per connection for mesh-grids and $208 per connection for mini-grids.

What it means

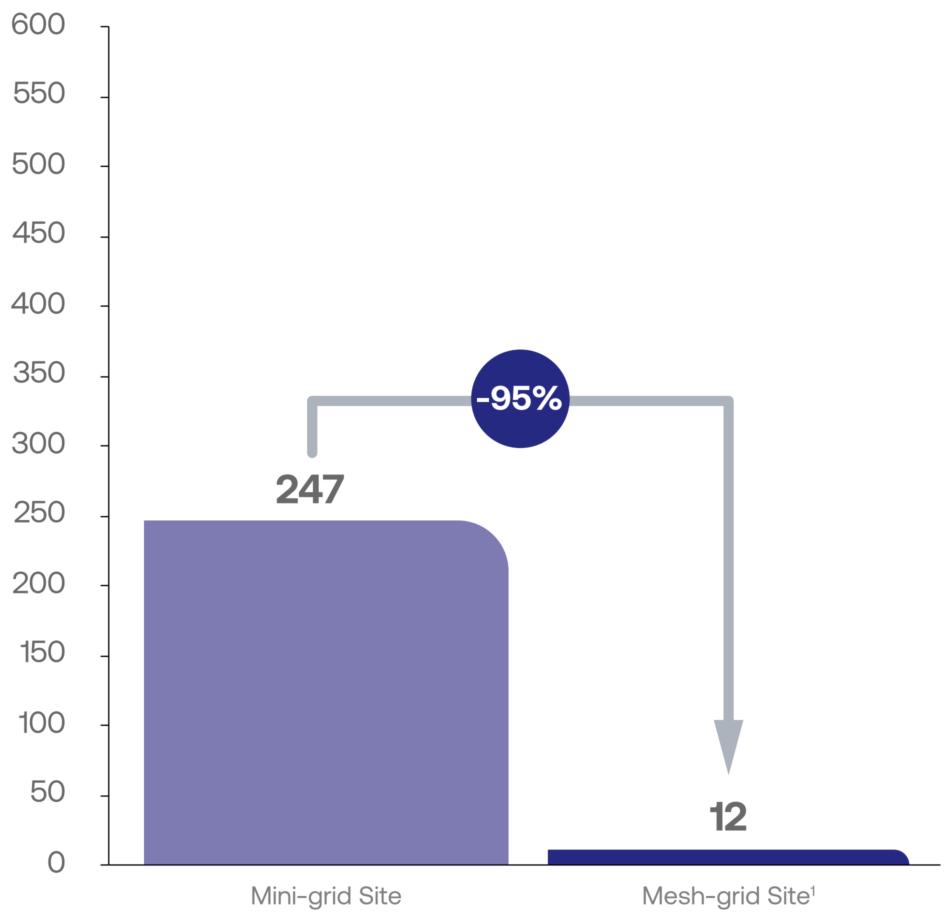
The lower distribution CapEx of mesh-grids enhances their scalability and cost-effectiveness, with greater flexibility in expanding the network.

A key driver of this cost reduction is the fact that mesh-grids do not require conventional distribution poles and wiring, as power is shared directly between neighboring households via 2.5SQMM cable at 50V DC.

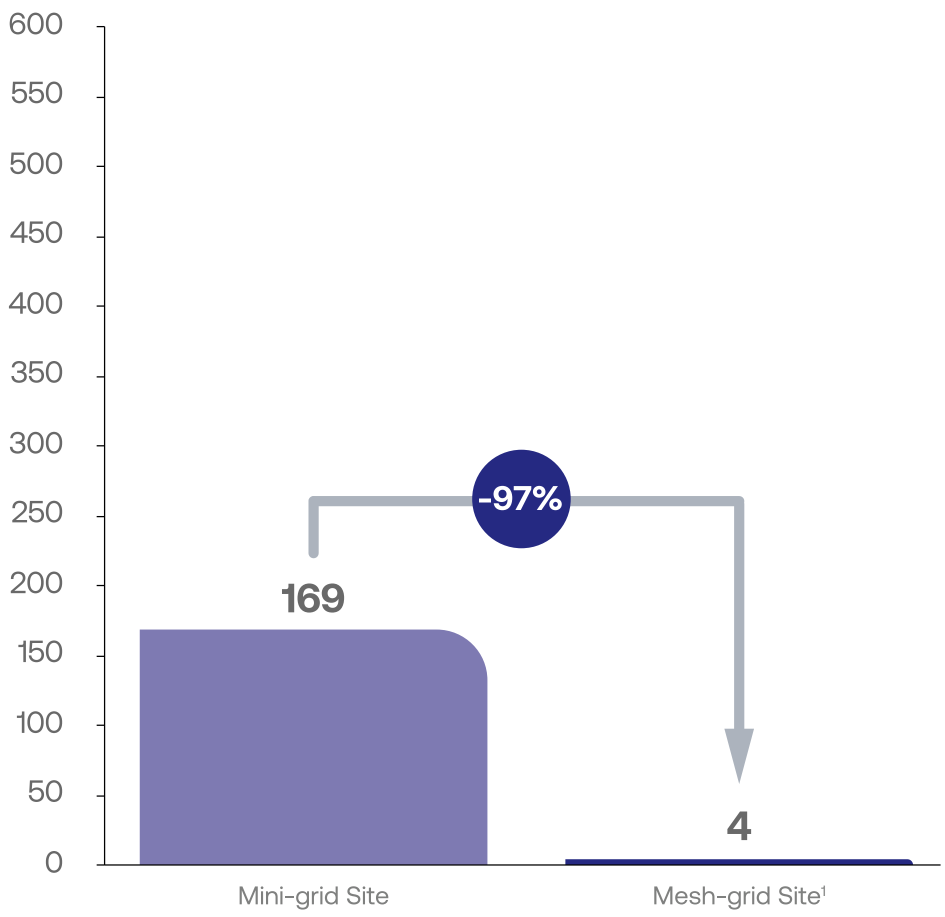
A previous Innovation Lab Insight on Grid Densification demonstrated the impact of proactively building distribution infrastructure and installing connections before customers make a financial commitment. While this approach led to higher site utilization rates, it required a substantial upfront CapEx investment.

While mesh-grids offer similar benefits to grid densification in terms of rapid and dense customer connection, the comparison is not one-to-one. In grid densification, distribution investments are layered onto an existing generation backbone, whereas mesh-grid deployments include the full generation and distribution system. As such, mesh-grids are not a direct substitute for grid densification, but they represent a parallel option for quickly expanding access—particularly where generation assets are not already in place.

Distribution CapEx per connection comparison, mesh-grid to mini-grid full deployment site ($)



Distribution CapEx per connection comparison, mesh-grid to mini-grid extension site ($)



1. Mesh-grid distribution costs do not include poles.
Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites

Differences between OpEx costs across sites are highly impacted by individual developer operational practices

What we're seeing

OpEx per connection at the mesh-grid extension site is 79% lower than the mini-grid control site at $7 per connection compared to $33 per connection.

However, OpEx per connection at the full deployment mesh-grid treatment site is significantly higher than the mini-grid control site at $28 per connection compared to $3 per connection.

What it means

OpEx per connection tends to vary depending on each developer's O&M structure.

Operations and management (O&M) costs at both mini-grid control sites are driven by Software-as-a-Service (SAAS) fees, fuel for diesel generators, servicing fees, staffing for security, operations, and system monitoring.

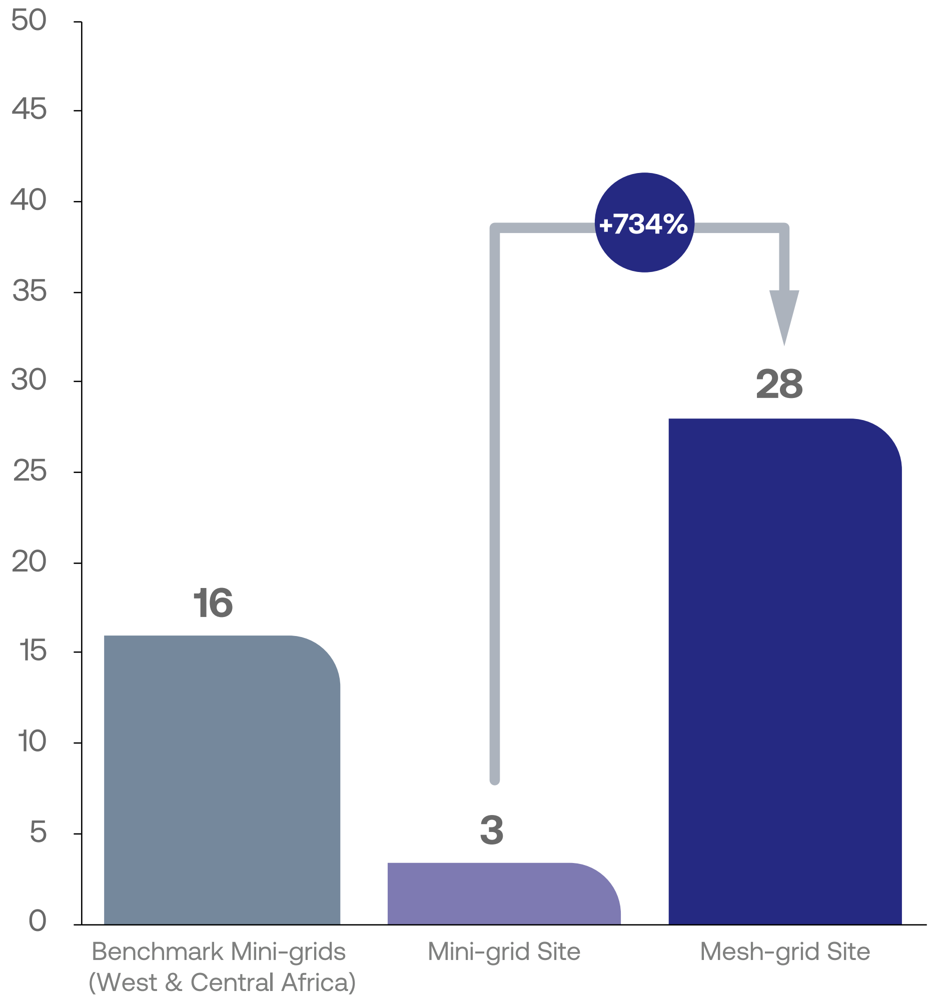
At the mesh-grid sites, O&M expenses include SAAS fees, labor costs for cleaning solar panels and transport allowances for servicing personnel.

Due to its proximity to the mini-grid control site, the mesh-grid extension site is able to leverage shared support services, reducing the need for dedicated maintenance staff and helping keep OpEx costs low.

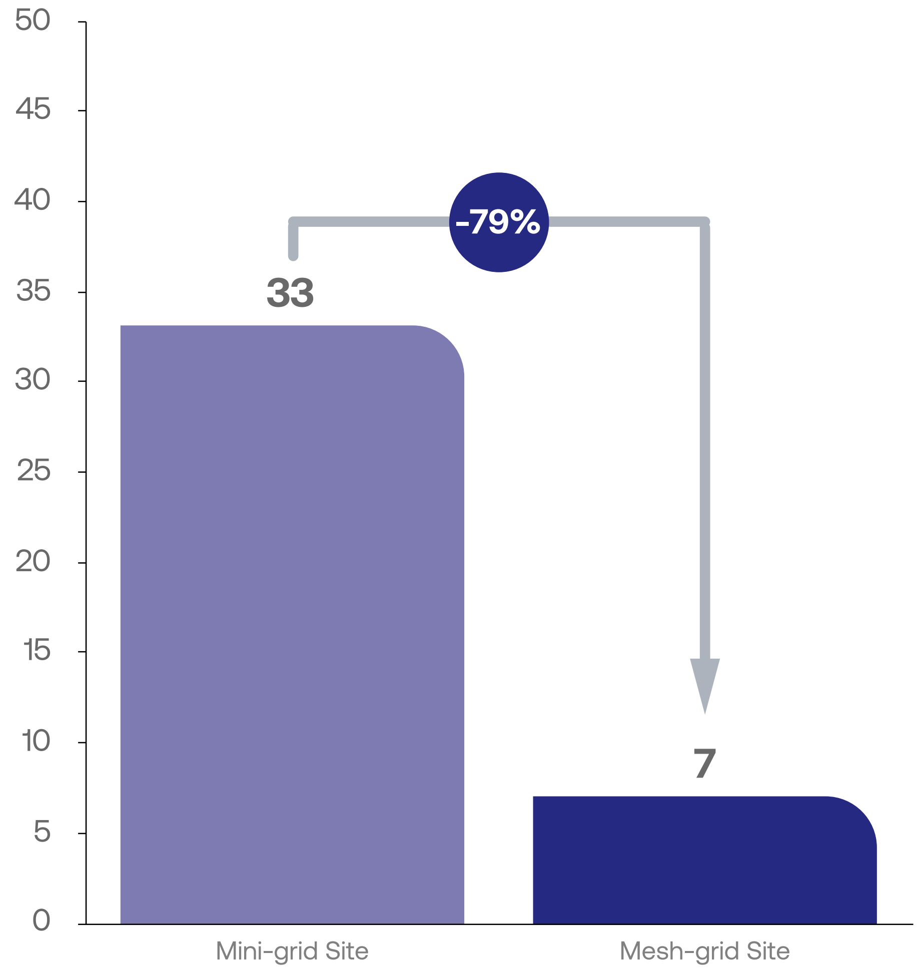
In contrast, the full deployment mesh-grid site requires dedicated resources that are not yet optimized to the level seen at the minigrid control site.

This suggests that OpEx efficiency for mesh-grids is highly context-dependent and is driven less by technology choice and more by operational design, location, and opportunities to share resources.

OpEx per connection comparison, mesh-grid to mini-grid full deployment site ($)



OpEx per connection comparison, mesh-grid to mini-grid extension site ($)



Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites
Mini-grid benchmark data: AMDA Benchmarking Africa's Mini-grids Report (2025)

Mesh-grids demonstrate faster deployment speeds than conventional mini-grids

What we're seeing

The full deployment mesh-grid treatment site has a speed of deployment 1.5 times faster compared to the mini-grid control site. The treatment site connected 143 customers over 1.5 months while the control site connected 200 customers over 3 months.

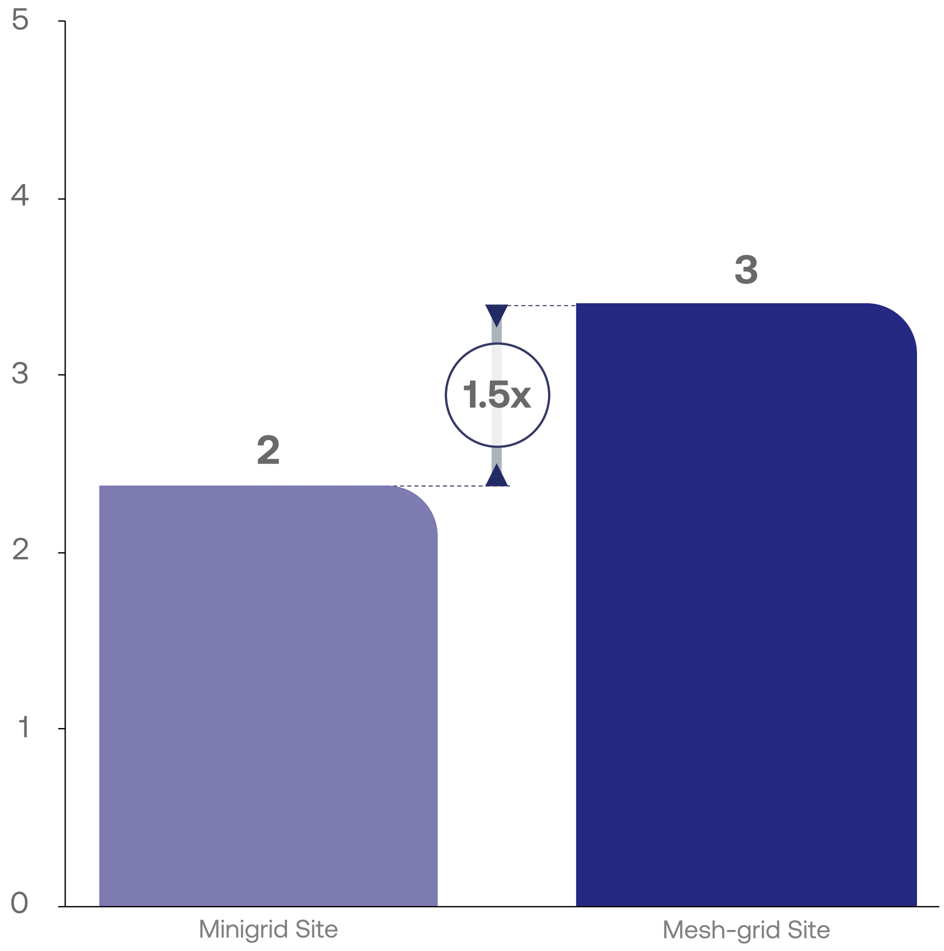
The speed of deployment at the mesh-grid extension treatment site was slower than the mini-grid site. The treatment site connected 50 customers over 2 months while the mini-grid control site connected 435 connections over 10.5 months.

What it means

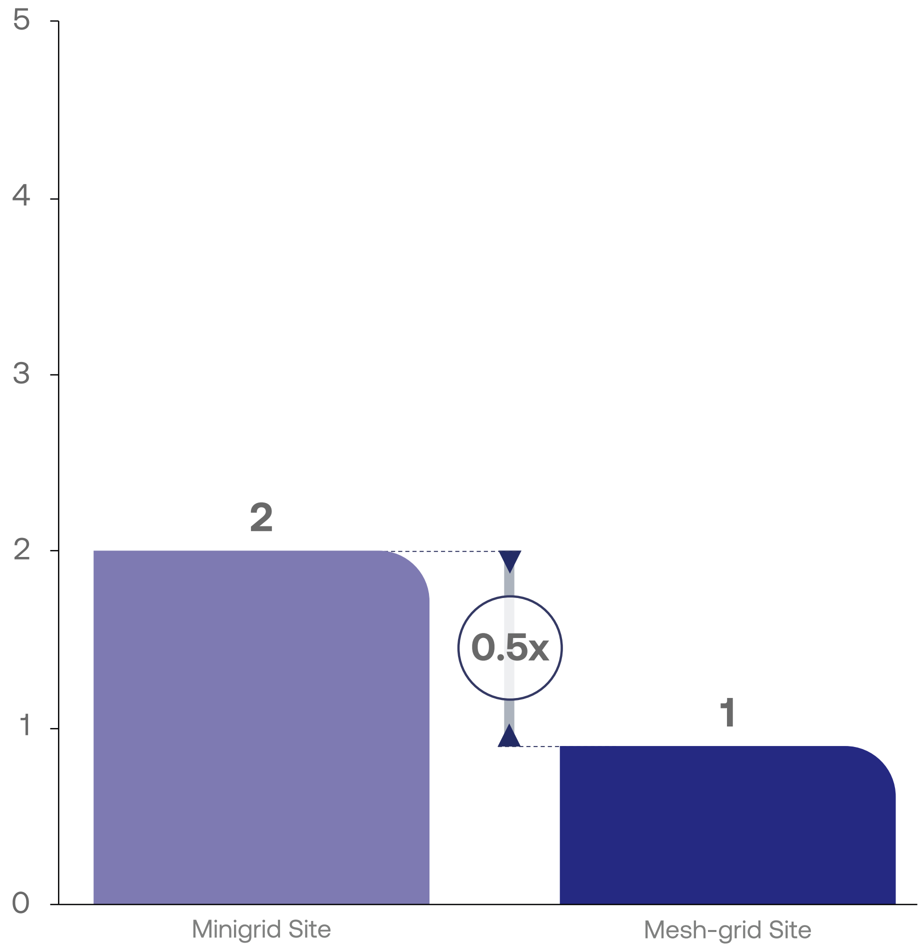
Full deployment mesh-grids are generally faster to deploy compared to conventional mini-grids because panels, batteries and pods are installed on individual houses without the need for extensive infrastructure for power distribution.

In contrast, the slower deployment observed in the extension case reflects the added complexity of the extension site configuration (PV panel on each household) which impacted the installation and commissioning processes.

Speed of deployment comparison, mesh-grid to mini-grid full deployment site (connections per day)



Speed of deployment comparison, mesh-grid to mini-grid extension site (connections per day)



Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites

02

Mesh-grids demonstrate higher reliability than mini-grids and maintain competitive revenue despite lower ACPU

Mesh-grids have high reliability, demonstrating >96% across both sites, compared to 27-60% for the mini-grid control sites

What we're seeing

The graphs show the average availability and the monthly and yearly reliability of the mesh-grid treatment sites and mini-grid control sites illustrating how consistently each system delivers power over time.

Availability refers to the percentage of time the mini-grid system is technically able to deliver power whether or not there is actual demand or usage while reliability (or uptime) is defined here as the percentage of time the grid provided stable electricity supply to consumers.

Over the course of the pilot, the mesh-grid sites experienced >96% reliability compared to 27-60% reliability at the mini-grid sites.

What it means

The decentralized design of mesh-grids, which distributes power generation and storage across multiple nodes, enhances reliability by reducing single points of failure, ensuring that local outages do not result in full system failure.

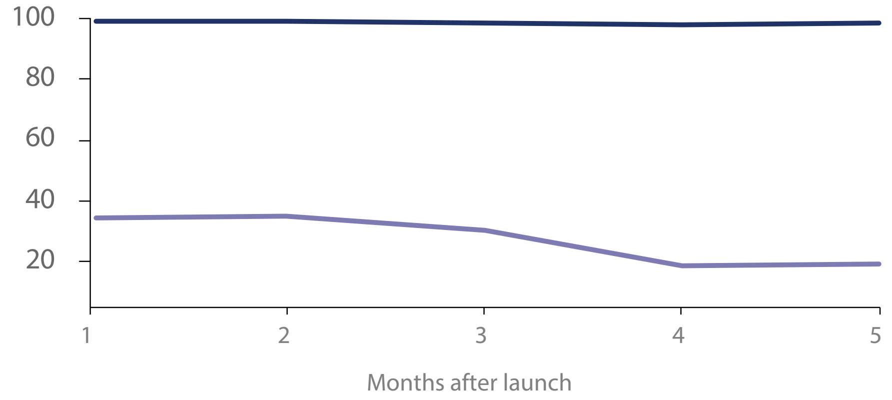
In comparison, the mini-grid sites are more vulnerable to single points of failure, particularly at inverters or batteries. Their longer operational history—4 years at the full deployment site and 15 months at the extension site—also means they're more affected by wear and tear compared to the newer mesh-grid systems. Developers logged average uptime of 93% at the full-deployment control site and 97% at the extension control site in the first six months, underscoring how ageing centralized components can erode reliability.

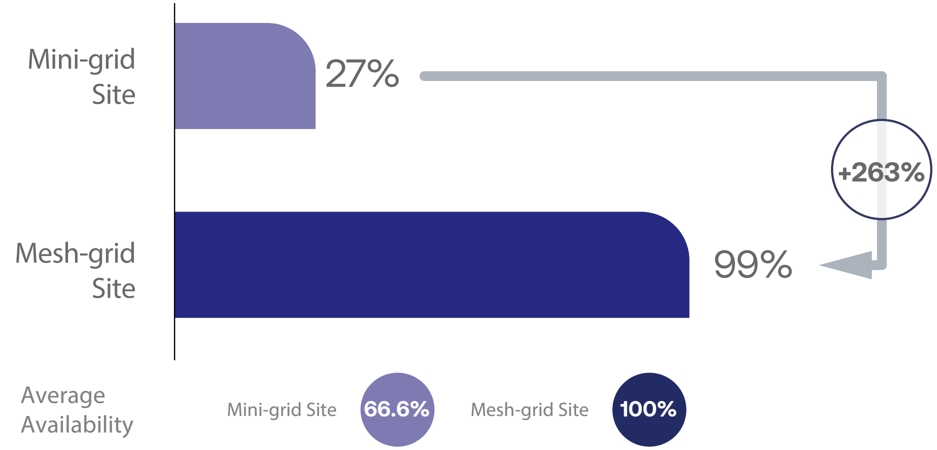
Monthly reliability comparison (%)

— Mesh-grid site — Mini-grid site

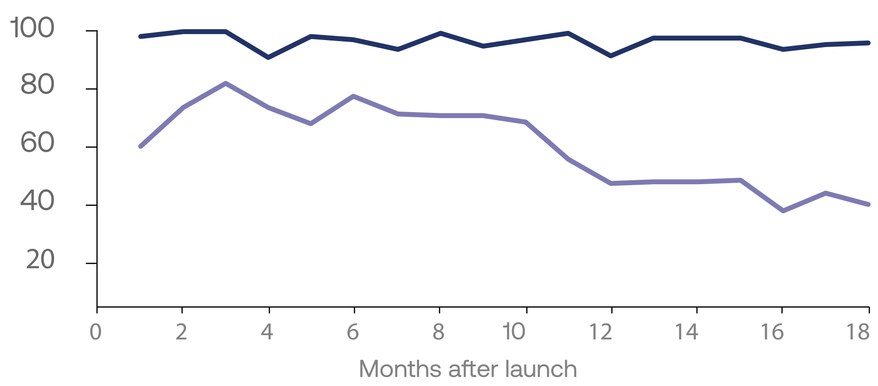
Average reliability comparison (%)

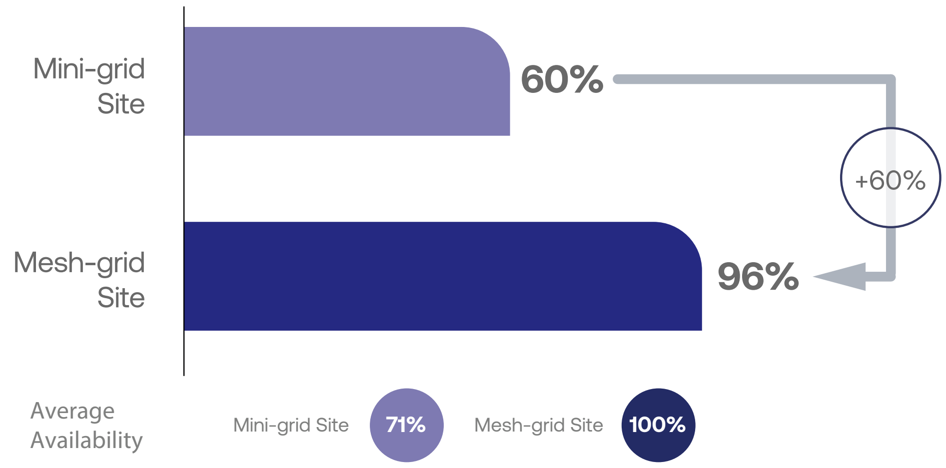
Full deployment site





Grid extension site





Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites
Note: Reliability is measured as the number of meter recordings received as a percentage of the expected recordings.
Mini-grid full deployment site: The developer reported a reliability of 93% and availability of 100% for the first 6 months after commissioning.
Mini-grid extension site: The developer reported a reliability of 97% and availability of 100% for the first 6 months after commissioning.

ACPU at the mesh-grids sites is lower than ACPU at the mini-grid sites by 51-58%

What we're seeing

ACPU at the mesh-grid treatment sites is lower than ACPU at the mini-grid control sites.

The full deployment mesh-grid treatment site has an average ACPU of 5 kWh/month compared to the mini-grid control site with an average ACPU of 11 kWh/month.

The mesh-grid extension treatment site has an average ACPU of 6 kWh/month compared to the mini-grid control site with an average ACPU of 13 kWh/month.

What it means

Mesh-grid site consumption is highly limited by the low power output of the mesh-grid units. The mesh-grid pods installed at the treatment sites have a capacity of 1.2 kW, making them better suited for household or small business loads (as further detailed in subsequent pages). Consequently, these sites host fewer productive-use or income-generating activities that typically drive higher consumption, especially when compared to the mini-grid sites.

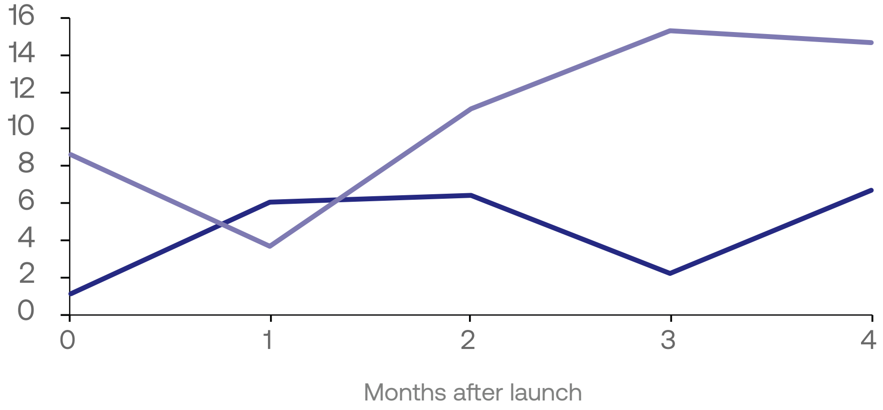
While the mini-grid sites have matured over time, enabling gradual growth in demand, mesh-grids may be less able to support increasing loads due to these inherent technical limitations.

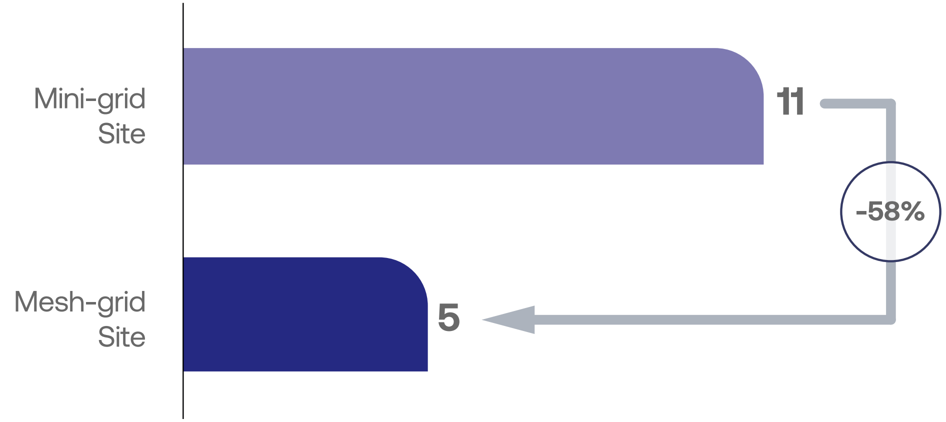
ACPU comparison (kWh/month)

Mesh-grid site   Mini-grid site

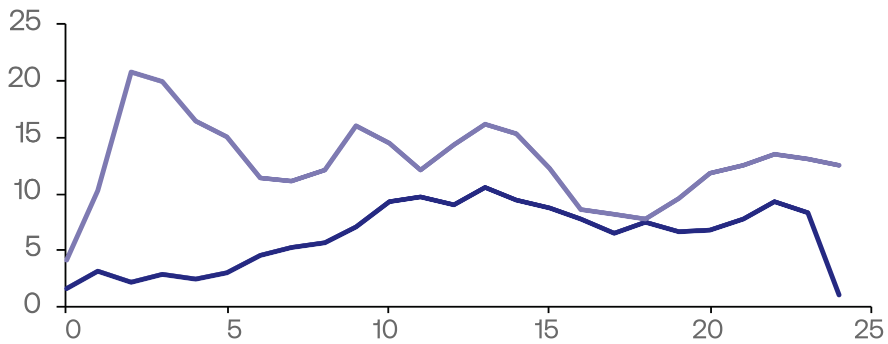
Average ACPU comparison (kWh/month)

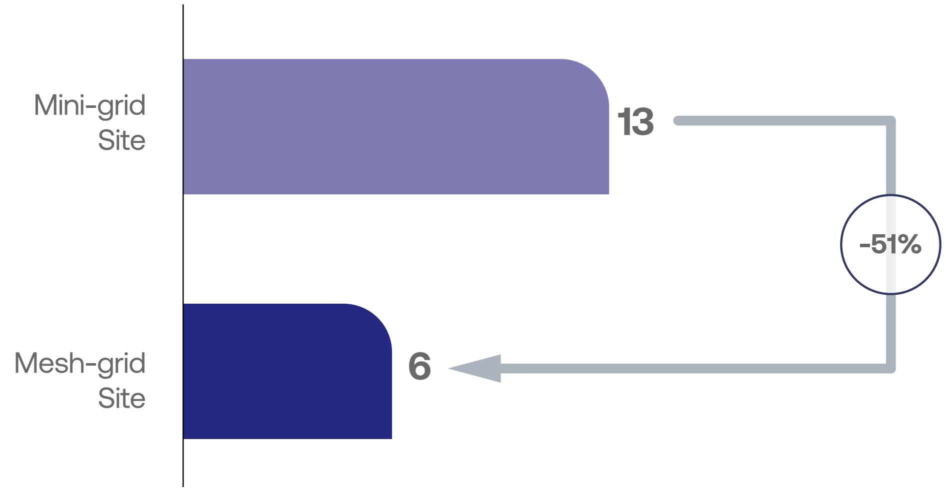
Full deployment site





Grid extension site





Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites

Extension mesh-grids demonstrate competitive ARPU compared to mini-grids despite lower ACPU

What we're seeing

Despite having lower ACPU, the mesh-grid treatment sites achieved higher ARPU compared to the mini-grid control sites.

The full deployment mesh-grid treatment site recorded 213% higher ARPU than the mini-grid control site while the extension mesh-grid site recorded 25% higher ARPU than the minigrid control site.

ARPU at the mini-grid control sites was calculated over the same time periods as their corresponding mesh-grid sites: Month 0 (commissioning) to Month 4[3] for the full deployment sites, and Month 0 to Month 24[4] for the grid extension sites to ensure a consistent comparison window and account for variations in customer growth and revenue patterns over time.

What it means

ARPU at the mini-grid sites has generally increased over time as demand has grown, highlighting how usage patterns evolve with customer familiarity and trust in the system.

Both mesh-grid treatment sites apply higher tariffs than the mini-grid control sites, primarily because mesh-grids in Nigeria are currently unregulated, while mini-grid tariffs are capped by regulator-approved rates. This gives developers greater flexibility to recover costs and improve revenues over time.

This also raises a key question around demand elasticity: is revenue primarily constrained by system capacity or could lower tariffs unlock higher consumption and push ARPU even further, revealing additional untapped demand?

The Lab's most recent research on **Tariff Reduction** suggests that a 41% decrease in tariffs could lead to a 58% rise in consumption, with the largest gains seen among low-consuming households. A similar trend may emerge among mesh-grid customers.

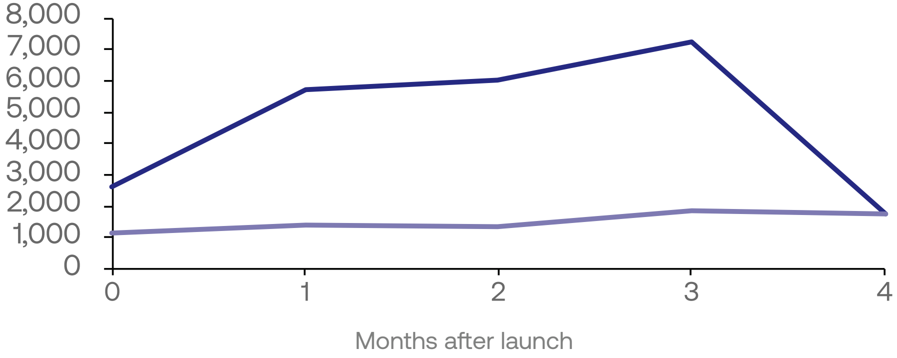
3. First five months of operations with consistent data.
4. First 24 months of operations with consistent data.

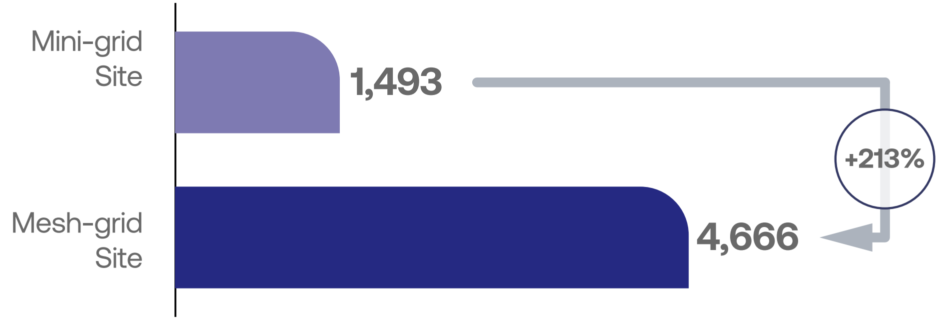
ARPU comparison (NGN)

— Mesh-grid site — Mini-grid site

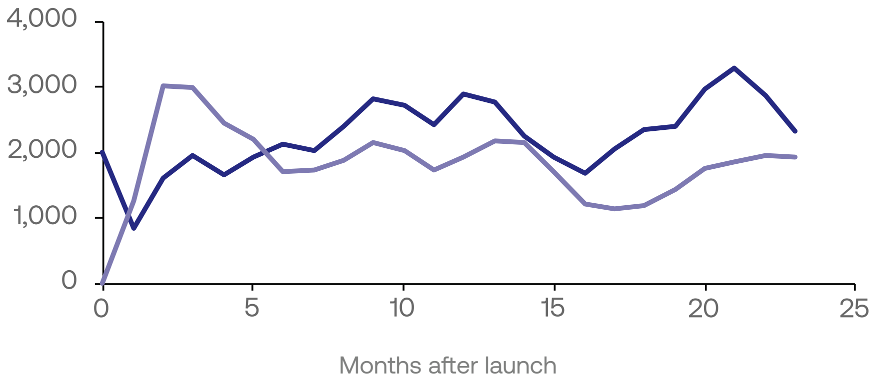
Average ARPU comparison (NGN)

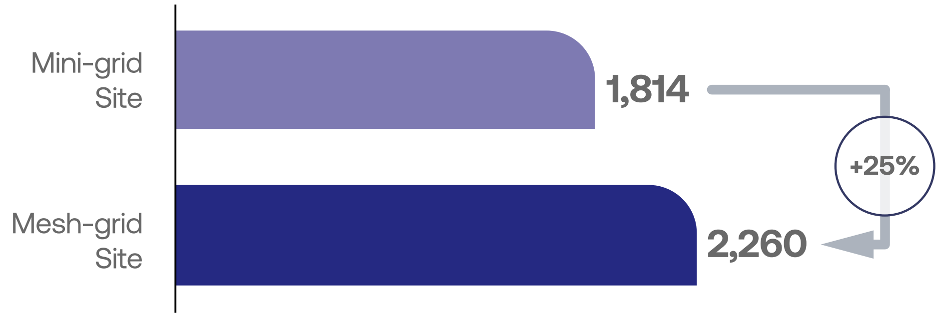
Full deployment site





Grid extension site





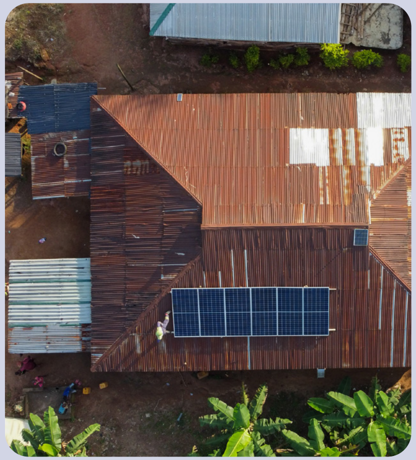
Source: Charts show CBIL developer data for 2 control sites and 2 treatment sites

Note: ARPU at the mini-grid control sites was calculated over the same periods as the mesh-grid sites: Month 0 (commissioning) to 4 for the full deployment site, and Month 0 to 24 for the grid extension site.

03

Mesh-grids are increasingly proving their potential for rapid deployment at scale

Case study: Mesh-grids are transforming rural energy access in Haiti, powering over 4200 households with reliable and affordable energy



To accelerate the transition to clean energy, Alina Enèji provided each connected household with two light bulbs and a fan at no cost, integrating electricity access with appliance financing to enhance customer affordability and energy adoption.

Overview

With **more than 46% of households in Haiti lacking access to electricity,** many communities remain entirely off-grid, relying on wood, charcoal, candles and kerosene lamps for basic energy needs.

The lack of access to affordable and reliable power has hindered the island's development, affecting communities and businesses and limiting the nation's ability to adapt to worsening climate events.

Alina Enèji, a Haitian project developer founded in 2021, is pioneering a decentralized, scalable electrification model using mesh-grids to bring affordable and renewable energy to more than **4200 households** in Haiti. Alina Eneji launched this project in the rural commune of Marchand-Dessaline with ongoing expansion around the Gonaïves and Plaisance communes.

By significantly reducing the cost per connection while maintaining high uptime and energy reliability, Alina Eneji is demonstrating how innovative decentralized energy solutions can bridge Haiti's energy gap faster and more affordably than conventional infrastructure.

Key Metrics

Cost per connection
$545

The average cost per connection at their mesh-grid sites is **$545, which is one-third of the $1,627 per connection cost** for minigrids in Haiti, as reported by the World Bank. Costs are expected to further reduce to $400 per connection for new connections driven by economies of scale with demand already exceeding 6000 additional connection requests in their current areas of operation

Electricity Tariff, $/kWH
0.79

Alina Eneji charges an average electricity tariff of $0.79/kWh (excluding VAT), providing a significantly more affordable alternative with **over 90% cost savings** for their customers compared to informal charging stations, where customers pay HTG 35 ($8/kWh) to charge a light bulb and HTG 15 ($11/kWh) for phone charging.

Note: This case study is examined in greater detail in GEAPPs report "Innovation to accelerate off-grid electrification in Haiti" (2025)

Sources: Alina Enèji monthly site data reports; Global Energy Alliance for People and Planet, Innovation to accelerate off-grid electrification in Haiti (2025) State of the Global Mini-Grids Market Report 2024

Alina Enèji's mesh-grid site has 48% lower CapEx per connection than minigrid systems, but incurs higher O&M costs

What we're seeing

CapEx per connection for Alina Enèji's mesh-grid site is more than 48% cheaper than benchmark data for minigrids in Africa.

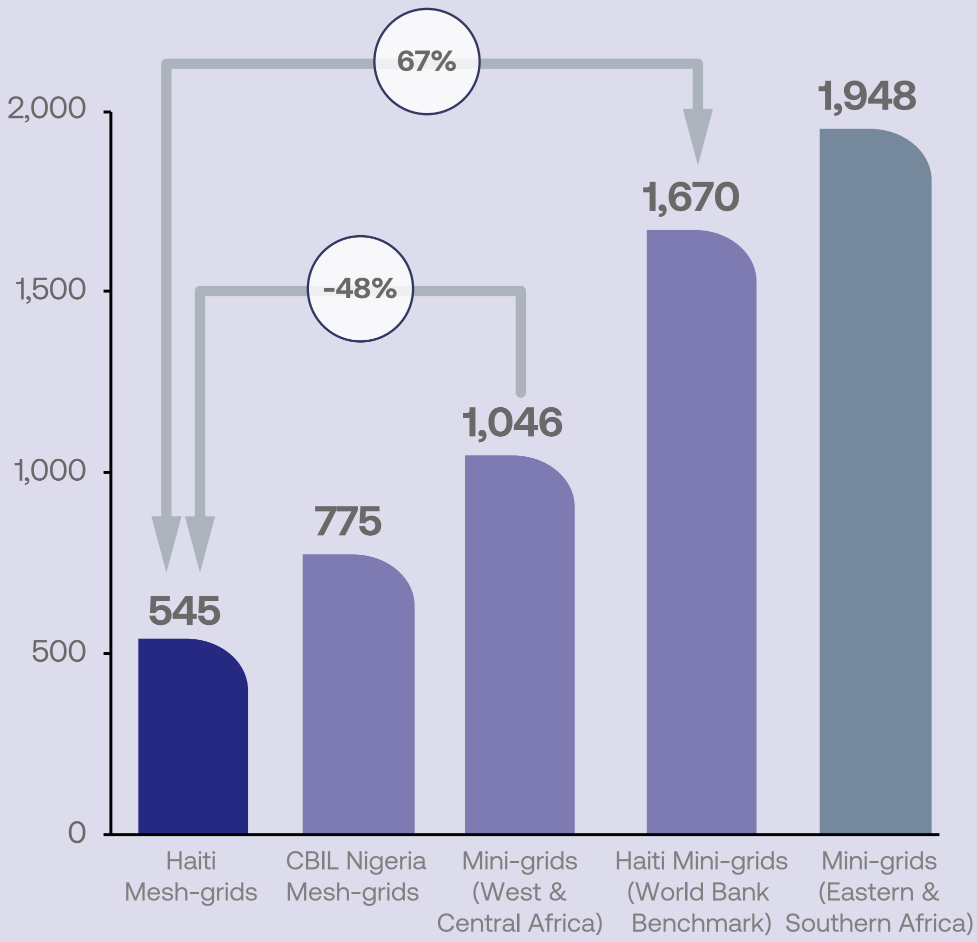
Yearly O&M costs for Alina Enèji's mesh-grid site are more than 40% higher than the O&M costs for the labs mesh-grid sites and minigrids in Africa.

What it means

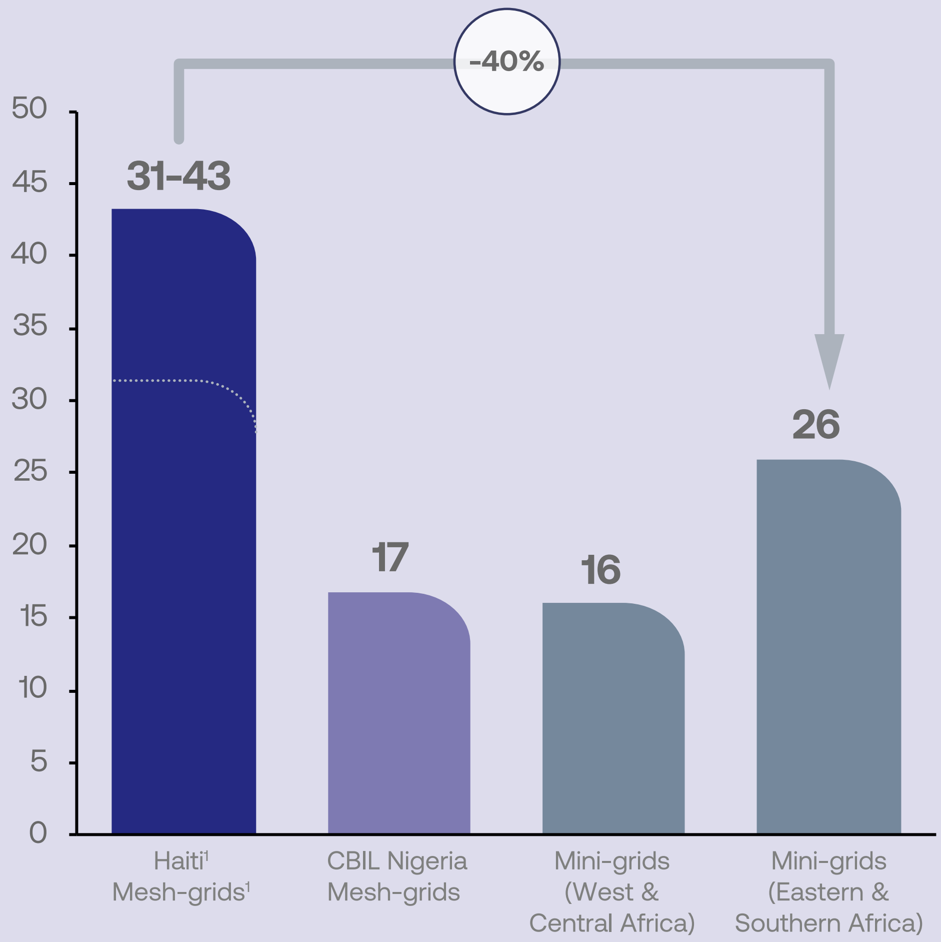
The lower CapEx cost for the Alina Enèji site is attributable to the scale of the installation (4200) and the higher proportion of Spokes (households) connected in the network (Alina Enèji has up to 10 Spokes per Hub).

The yearly O&M costs at Alani Enèji's mesh-grid site include SAAS fees, grid maintenance and repair costs. These costs have been significantly impacted by rising FX rates and challenging macro-economic conditions in Haiti.

CapEx comparison, Haiti mesh-grids to CBIL mesh-grids and African mini-grids (kWh per month)



Yearly O&M costs per connection comparison, Haiti mesh-grids to CBIL mesh-grids and African minigrids ($ per connection)



1. The upper limit figure of $43 per connection is calculated from O&M data from July 2023 to January 2025. GEAPP, Innovation to accelerate off-grid electrification in Haiti (2025) reports O&M costs of $31.32 per connection
Sources: Alina Enèji monthly site data reports; CBIL Nigeria Mesh-grids: Average of lab data for Nigeria mesh-grids; Minigrid benchmark data: AMDA Benchmarking Africa's Minigrids Report (2025)

Alina Enèji's mesh-grid demonstrates high system reliability, and strong ARPU, but ACPU is lower than benchmarks

What we're seeing

The monthly ACPU on the Alina Enèji site is 4 kWh, which is lower than African minigrids, where monthly ACPU ranges from 10 kWh to 24 kWh per user.

The ARPU of $2.67 per kWh on the site is comparable to household revenue levels seen in African minigrids.

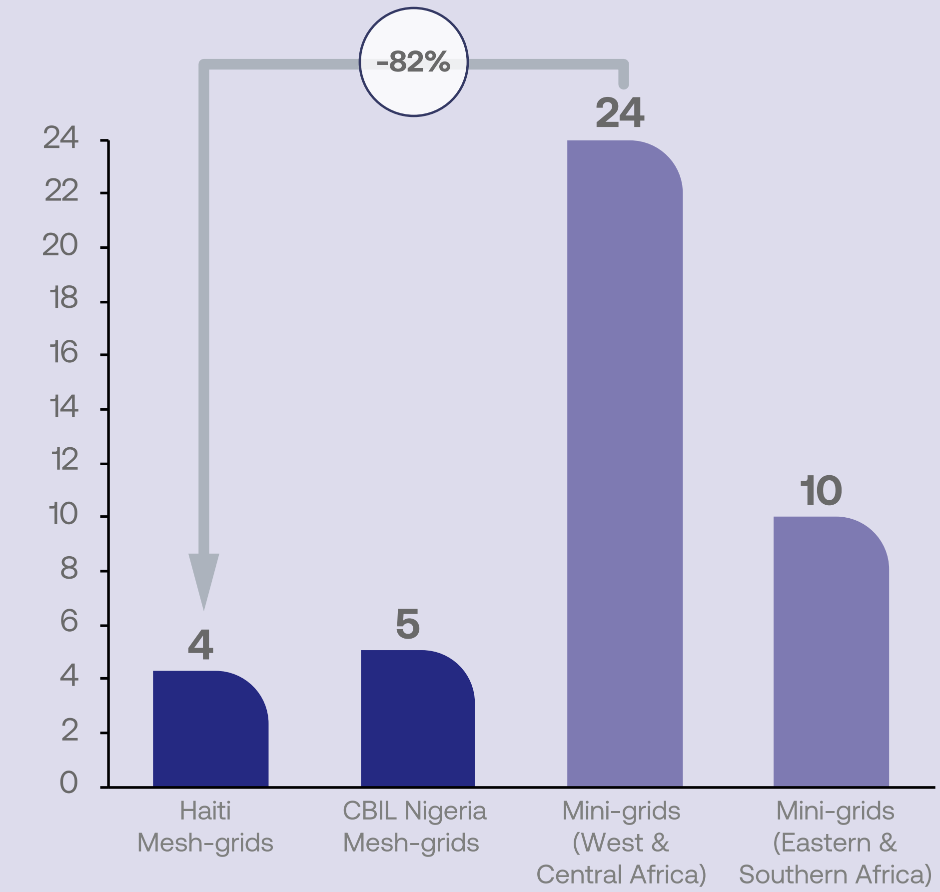
Alina Enèji's site charges a tariff of $0.79/kWh, which is 85% higher than the higher end of minigrid tariffs as observed in West & Central Africa, where rates peak at $0.40/kWh.

What it means

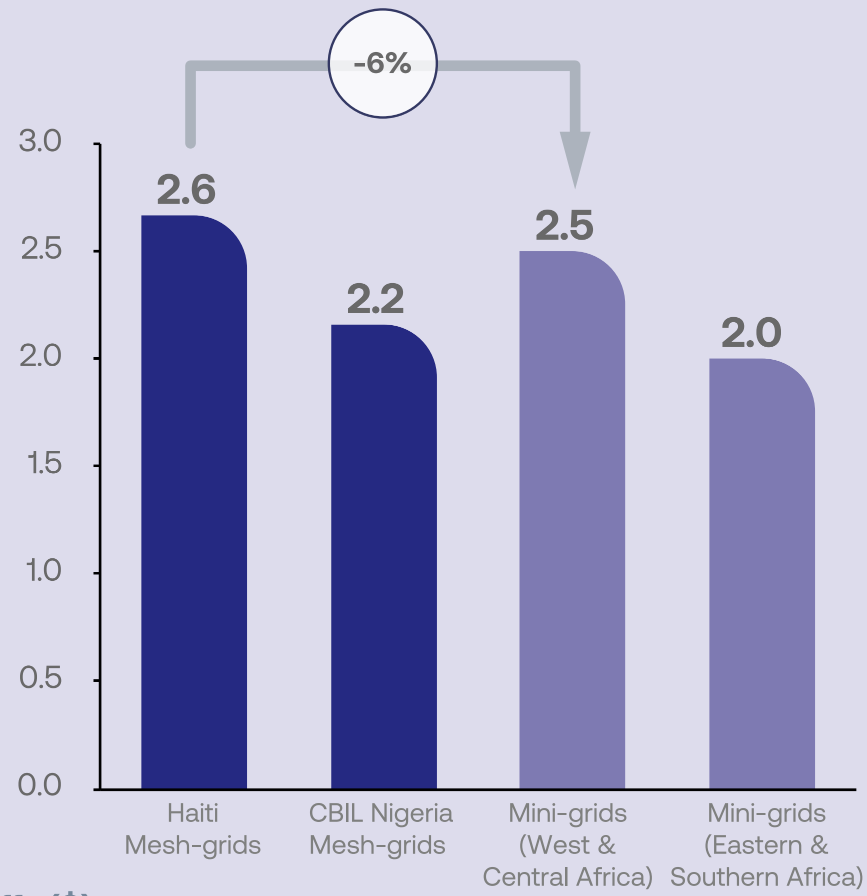
At Alina Enèji's mesh-grid site in Haiti, ACPU is lower than in minigrid benchmarks, reflecting the limited presence of productive-use customers and the high share of residential households.

Despite this, ARPU remains competitive, driven by exceptional system reliability (98% uptime) and higher—but still affordable—tariffs. Customers are willing to pay because the mesh-grid offers reliable, clean electricity at up to 90% lower cost than informal sources like kerosene or phone charging kiosks common in this community.

ACPU comparison, Haiti mesh-grids to African mini-grids (kWh per month)



ARPU comparison, Haiti mesh-grids to African mini-grids ($ per kWh)



	Haiti Mesh-grids	CBIL Nigeria Mesh-grids	Mini-grids (West & Central Africa)	Mini-grids (Eastern & Southern Africa)
Reliability	98%	98%	89%	86%
Tariffs ($)	0.79	0.25	0.25	0.39

Sources: Alina Enèji monthly site data reports; CBIL Nigeria Mesh-grids: Average of lab data for Nigeria mesh-grids; Minigrid benchmark data: AMDA Benchmarking Africa's Minigrids Report (2025)

04

Mesh-grids are emerging as a scalable, cost-effective solution for energy access despite uncertainty surrounding PUE loads and long-term performance

Community Insights from the Mesh-Grid Extension Site: Mesh-grids provide a reliable, cost-effective energy solution for unelectrified communities

Mesh-grid extension site community profile

Average number of members living in household	12
Average age of customer	34
% of customers that have completed secondary school	66%
Income source	Farming (61%)

Past energy sources

- Prior to the installation of the mesh-grids, this community relied on torches (44%) and solar lanterns (27%) for lighting
- Customers were eager for the mesh-grids to be operational, and were motivated by appliance usage (39%) and brighter light (34%)
- Customers envisioned cold storage of food (39%) and income generating activity with their newly powered appliances (32%)

"My aim is to use the mesh-grid for a fan at home and a fridge to store food. My wife can even do business of selling cold water".

– Mesh-grid Treatment Site Customer

New energy sources

- After getting connected to the mesh grids, this community is making the most of their connections:
  - 100% of customers have improved lighting
  - 15% of customers are using e-cooking solutions
- The developer is exploring options to bring even more income generating machinery online including rice milling machines

"Our home is now like one in the city, not village. At night, we can move around in the light, even charge our phones and use our fans for the hot weather. So it is very useful to me and my family".

– Mesh-grid Treatment Site Customer

Source: CBIL baseline survey conducted on customers at a developer's mesh-grid site.

However, the productive use potential of mesh-grids to power high energy machinery for businesses is still uncertain

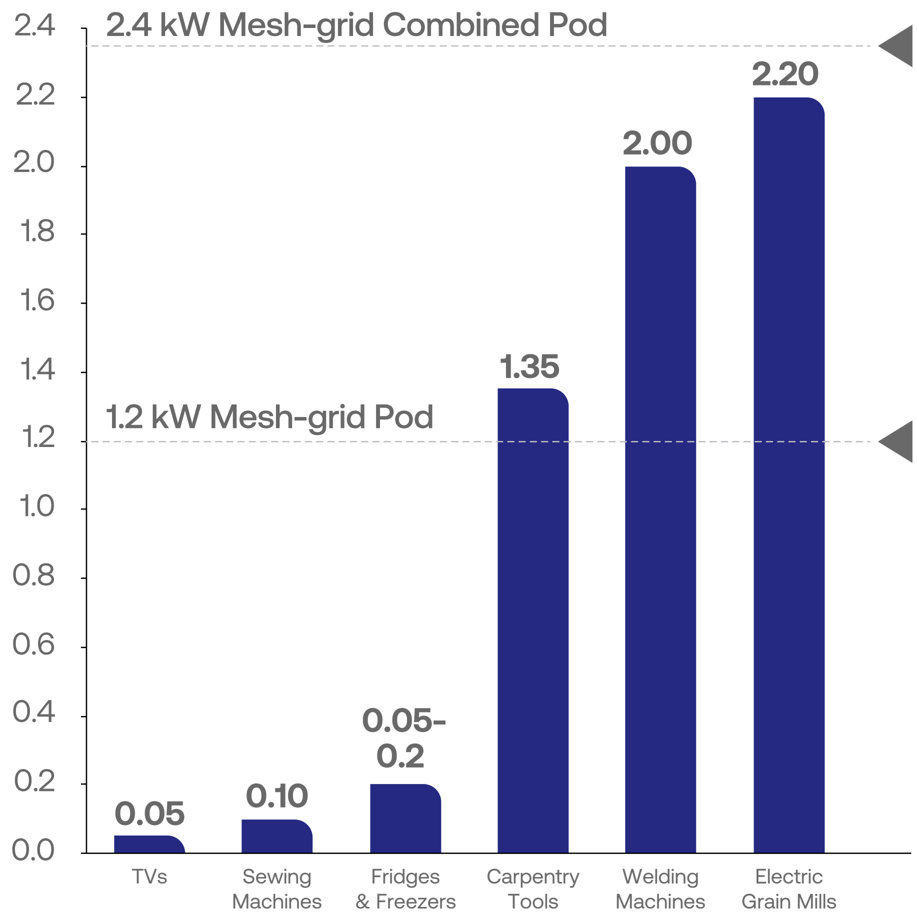
While mesh-grids provide sufficient energy for households, one of their primary limitations has been their relatively low power output, typically around 1.2 kW per individual system, limiting their ability to serve productive use customers with high load demand.

Power requirements for common productive use appliances vary significantly:

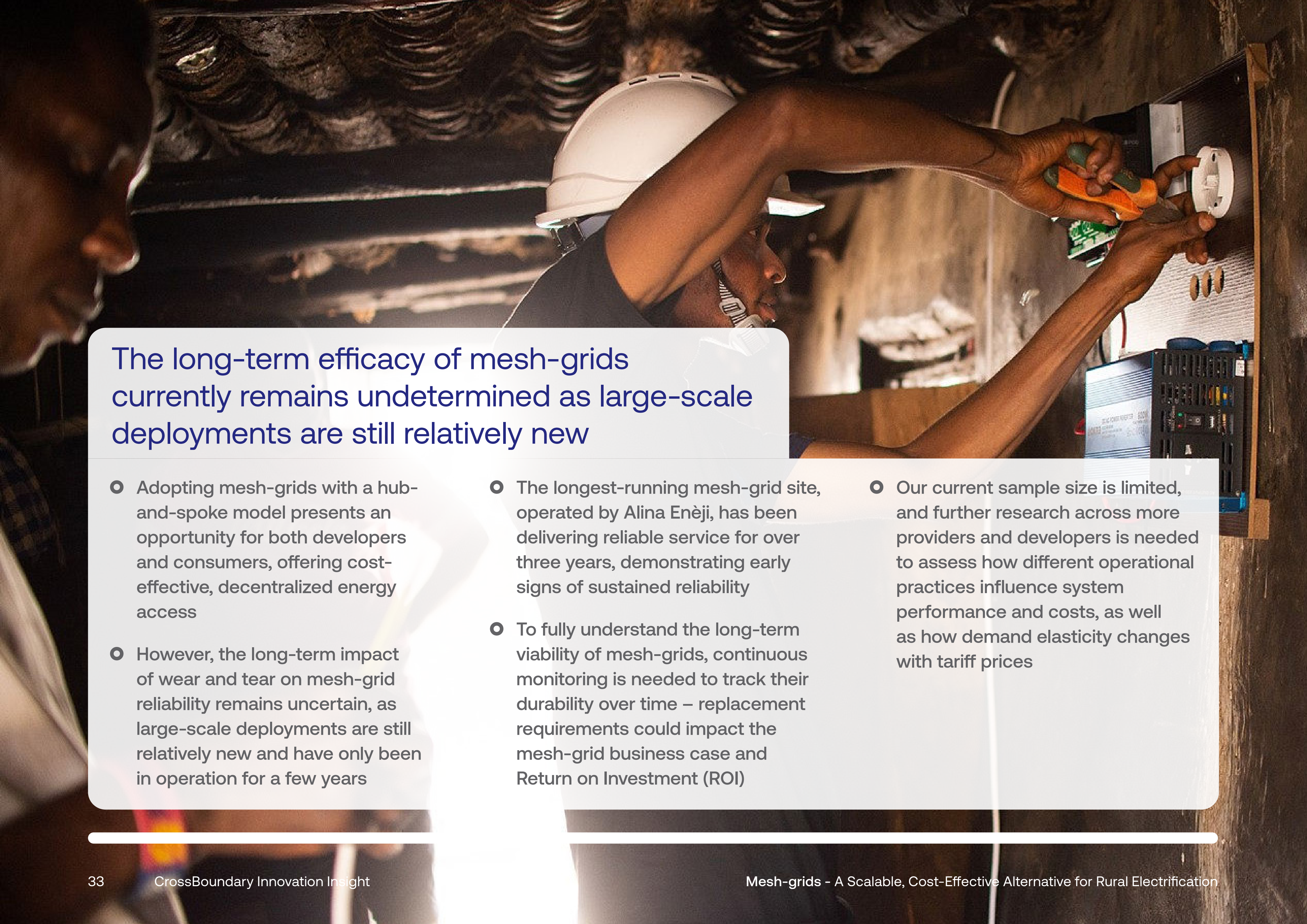
- Low-energy appliances, such as TVs (0.05 kW), sewing machines (0.1 kW), and refrigerators/freezers (0.05–0.2 kW), can be easily supported by mesh-grids.
- Medium-power tools, including electric saws and drills (0.5–2.2 kW), and welding machines (1–5 kW), may be supported depending on energy availability and system configuration.
- However, high-power machinery such as grain mills (2–6 kW) generally exceed the capacity of standalone mesh-grids, making mini-grids or hybrid models more suitable for these applications.

Leading mesh-grid technology providers are actively testing system configurations to enhance power output, aiming to reach up to 2.4 kW to 4.8 kW per connection by combining mesh-grid pods.

Average Power Rating (kW)



Source: CBIL Developer Data



The long-term efficacy of mesh-grids currently remains undetermined as large-scale deployments are still relatively new

- Adopting mesh-grids with a hub-and-spoke model presents an opportunity for both developers and consumers, offering cost-effective, decentralized energy access
- However, the long-term impact of wear and tear on mesh-grid reliability remains uncertain, as large-scale deployments are still relatively new and have only been in operation for a few years
- The longest-running mesh-grid site, operated by Alina Enèji, has been delivering reliable service for over three years, demonstrating early signs of sustained reliability
- To fully understand the long-term viability of mesh-grids, continuous monitoring is needed to track their durability over time – replacement requirements could impact the mesh-grid business case and Return on Investment (ROI)
- Our current sample size is limited, and further research across more providers and developers is needed to assess how different operational practices influence system performance and costs, as well as how demand elasticity changes with tariff prices

The lab will continue to track data on mesh-grids focusing on key unanswered questions such as their potential for productive energy use, long-term performance and cost effectiveness

Additionally, data from other suppliers will be essential for gaining a more comprehensive understanding of mesh-grid viability. We invite collaborators to share insights and contribute to advancing research in this space.

Please contact mini-gridslabs@crossboundary.com for collaboration opportunities.

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And by the following developers:

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The Lab's *Innovation Insight* series provides ongoing, early insights on the prototypes so mini-grid developers, governments, and funders can act on the results as they emerge. All results and analysis in these series is therefore shared as *actionable business intelligence* rather than scientific evidence.

While these series are not intended to meet the standards of an academic paper, the Lab will publish more complete reports at the end of each prototype, and has partnered with University of Massachusetts Amherst, Rochester Institute of Technology, and Duke University to publish academic papers on certain prototypes.

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