RMI

Harvesting Sunshine

How Productive Uses of Minigrid Electricity Make Farmers Richer and Energy Cheaper

RMI / September 2024

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Habiba Daggash, Ayodeji Ojo, Fola Aminu, Zihe Meng, Scarlett Santana, Suleiman Babamanu, and Andrew Allee, *Harvesting Sunshine: How Productive Uses of Minigrid Electricity Make Farmers Richer and Energy Cheaper*, RMI, 2024, **https://rmi.org/insight/harvesting-sunshine**.

About RMI
RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing.

Acknowledgments

This report was made possible by the support of the African Climate Foundation. It features the results of the Energizing Agriculture Programme (EAP) Agriculture-Energy Innovation Accelerator, which was funded by the Global Energy Alliance for People and Planet (GEAPP).

The authors thank the EAP's partner companies who codesigned and implemented the projects featured here, as well as peer reviewers who offered their insights and perspectives on this work.

EAP partner companies

ACOB Lighting Technology*
Afrimash*
Babban Gona Farmer Services Nigeria*
Coldbox Store*
ColdHubs
Ecotutu
Energy Excell Systems and Solutions*
Farm Warehouse*
GVE Projects
Husk Power Energy Systems*
Koolboks
Metro Africa Xpress (MAX)*
Muhat Nigeria*
Nayo Tropical Technology
One Acre Fund*
Prado Power Nigeria Mini-Grid*
Powergen Renewable Energy Nigeria*
Releaf Marketplace Nigeria*
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i Asterisked partners are featured in Section 3 case studies.

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Acronyms

ACPU	Average consumption per user
BnS	Buy-and-sell
CBN	Central Bank of Nigeria
CPO	Crude palm oil
EAP	Energizing Agriculture Programme
EV	Electric vehicle
E2W	Electric two-wheeler
FFB	Fresh fruit bunch
FFS	Fee-for-service
ICE	Internal combustion engine
IRR	Internal rate of return
kVA	Kilovolt-ampere
kWh	Kilowatt-hour
kWp	Kilowatt-peak
LCOE	Levelized cost of electricity
m^3	Cubic meter
NGN	Nigerian naira
NPV	Net present value
O&M	Operations and maintenance
OAF	One Acre Fund
PAYGO	Pay-as-you-go
PKO	Palm kernel oil
PUAFF	Productive Use Appliance Financing Facility
PUE	Productive use of energy
PV	Photovoltaics
TCO	Total cost of ownership

Executive Summary

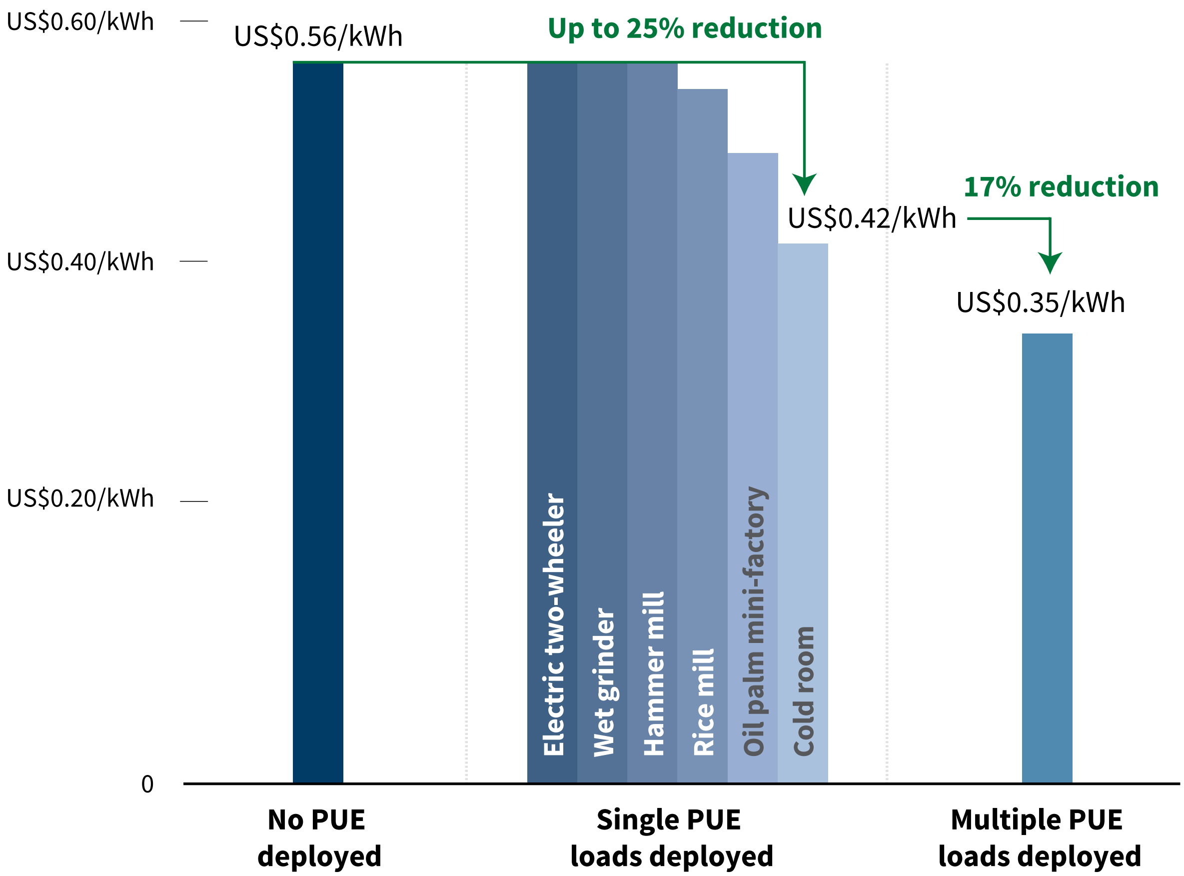
Women at Coldbox Store's Cold Room in Kiguna, Nasarawa state. Photo credit: TNF Media

Electricity transforms lives by powering appliances, machines, and devices that provide modern household conveniences and drive efficiency in businesses and industries. To maximize the benefits of energy access investments, incentives for energy end use are crucial. Nigeria's 170 minigrids — stand-alone solar + storage systems that serve as rural utilities throughout the country — show the risk of not supporting energy supply and use in tandem. These systems are the cheapest way to electrify many off-grid communities. Yet, they are underutilized because, on average, customers each spend less than US$2 monthly on power, often due to the inability to afford equipment. Many utilities have cut supply hours and failed to maintain their grids as low sales render them near insolvent.

Productive uses of energy (PUEs) change lives and transform power system economics, reducing the cost of producing electricity by up to 50%.

Some minigrids are bucking the trend as their customers adopt income-generating productive uses of energy (PUEs) that raise electricity sales and boost household incomes. Recognizing agriculture as the mainstay of Nigeria's rural economies, the Energizing Agriculture Programme (EAP) saw the potential of agricultural PUEs to uplift minigrid utilization and farmer incomes. This report narrates the EAP's experience deploying and operating 269 mills, freezers, EVs, and other equipment at minigrids across the country. It also distills the lessons learned from testing business models that deliver these machines through Nigerian equipment suppliers and service providers (i.e., PUE companies).

Exhibit ES1 **Effect of deploying PUE equipment on the levelized cost of electricity (LCOE) of an isolated minigrid**



RMI Graphic. Source: EAP analysis

EAP pilot data shows that a single walk-in cold room can reduce the cost of producing minigrid electricity[ii] (see Exhibit ES1) from the US$0.56 per kilowatt-hour (kWh) of a typical 50-kilowatt peak system to US$0.42/kWh, a 25% reduction. This US$30,000 cold room investment can raise minigrid electricity sales sixfold. A larger minigrid that can accommodate 19 mills and 10 chest freezers can reduce electricity costs from US$0.69/kWh to US$0.35/kWh after PUE deployment (see Section 4). **Our findings show that a minigrid that capitalizes on economies of scale and PUE customers can produce electricity at half the cost of a minigrid serving predominantly residential customers.** This finding reinforces a body of work showing that no other cost reduction strategy has a larger effect on minigrid economics than helping customers use increasing amounts of energy.[1] In addition, EAP pilots showed that strong anchor electricity customers provided a clear incentive for power reliability and quality, as local businesses were vocal about the costs of unexpected downtime, and as minigrid operators saw the opportunity costs of not selling to these customers as much as possible.

ii On a levelized cost of electricity basis, which divides all electricity sold by all costs incurred over the 20-year project life.

This report features the results of five teams of Nigerian energy and agriculture entrepreneurs putting minigrid electricity to work across five agricultural value chains: cold storage for fishers, electric mobility for farm logistics, electric motor retrofits, oil palm processing, and rice milling. Each team piloted PUE equipment using a scalable business model led by a Nigerian company. In the case studies examined here, equipment deployed by the EAP-enabled entrepreneurs to move away from fossil fuel–powered machines to electric alternatives and reduce their energy costs by up to 82%. The EAP's US$60,800 investment in this equipment created nearly 70 direct jobs and more than US$110,000 in value-added commodities (see Exhibit ES2).

PUEs improve agribusinesses by boosting efficiency and reducing energy costs by up to 80%.

Exhibit ES2 Summary of the technical and economic performance of equipment deployed by the EAP accelerator

	Cold storage	Electric mobility	Electric motor retrofits	Oil palm processing	Rice milling
Energy cost savings	No previous energy use	20%	44%–82%	82%	44%
Yield improvement	1,250 kg less fish lost to spoilage	—	—	57 liters more oil per ton of fruit (+50%)	Share of broken grains reduced from 55% to 30%
Direct jobs	29	7	17	7	9
Equipment deployed	1	6	9	9 (3 electric, 6 nonelectric)	5
Equipment cost	US$27,094	US$10,317	US$7,528	US$10,700	US$5,115
Value generated for entrepreneur	US$3,890	Not applicable	**Guinea corn flour:** US$1,960 **Soyabean paste:** US$10,700	**Fees:** US$4,370 **Palm oil:** US$63,000	**Fees:** US$458 **Rice sales:** US$26,400

RMI Graphic. Source: EAP pilot data

Realizing the promise of PUE requires an ecosystem of partners to power, finance, deploy, and maintain the machines.

The EAP pilot teams succeeded by leveraging partners' resources and expertise to:

- Identify equipment that meets customer needs and deliver it through affordable financing,
- Integrate and power equipment with minigrid infrastructure, and
- Provide on-ground capacity for equipment operations and maintenance (O&M) (including after-sales service).

RMI provided on-hand technical assistance to overcome challenges from equipment troubleshooting to historically fraught macroeconomic conditions (Section 1). After nearly three years from business model design to monitoring and evaluation, the EAP experience has revealed six key challenges to scaling up these energy-agriculture solutions and five recommendations for the public, private, and philanthropic partners who can address them.

Challenges

1. PUE companies struggle to access financing due to their lack of maturity and small-scale operations. Local financiers prefer established companies with consistent revenues.
2. Pay-as-you-go (PAYGO) models that make PUE affordable are not being implemented because of the high cost of administering loans in rural areas. Local financiers charge exorbitant interest rates for consumer financing, and PUE companies cannot offer equipment on credit because of the cost and operational complexity of handling payment collections.
3. PUE companies are too cash-strapped to maintain large inventories, and importing equipment is time-consuming, so there are long lead times when customers need equipment or parts replaced. Finding alternative suppliers can be a monthslong process.
4. PUE companies have limited rural footprints and staffing, which leads to poor O&M service provision. Delays cause customers to tamper with equipment, resulting in total breakdown and reverting to diesel equipment.
5. There is a mismatch between equipment in the market and customer needs. This leads farmers to overwork available equipment, resulting in frequent breakdowns and downtime, discouraging future customer adoption.
6. Volatile macroeconomic conditions (high inflation, currency devaluations, and policy inconsistencies) disrupt operations, increase costs, and reduce customer demand.

Recommendations

1. **The government should use policy levers and financial resources to ease PUE companies' supply chain challenges and resource constraints. It should:**

    - Simplify import classifications and duties for faster equipment import.
    - Exempt PUE equipment from customs duties to lower costs.
    - Extend the concessional loans and advisory support offered to farmers through state development banks to PUE companies.
    - Prioritize PUE in rural electrification policies and coordinate energy-agriculture interventions to facilitate cross-sectoral collaboration.
    - Establish quality standards for PUE appliances to ensure efficiency, longevity, and safety.

2. **PUE companies must guarantee equipment reliability through prompt O&M service delivery, and efficiently implement PAYGO models to boost affordability. They should:**

    - Invest in data collection to understand customer needs and work with manufacturers to design for those needs.
    - Partner with other rural service providers to share infrastructure and business functions (e.g., warehousing, payment collections) and lower operating costs.
    - Build local O&M capacity by stocking spare parts, training technicians, and investing in logistics networks near customer locations.

3. **Minigrid developers must support PUE and energy supply in tandem. Support for energy-only solutions leads to underutilized and unsustainable minigrids. They should:**

    - Survey PUE opportunities before minigrid construction and develop a plan to realize them, including building necessary partnerships and business models.
    - Build and retain expertise in PUE (e.g., partnership building, equipment appraisal, site selection, and integration) through staff retention or standardized training.

4. **Investors must support nascent companies to realize the US$120 billion PUE market opportunity in sub-Saharan Africa. They should:**

    - Offer working capital loans and inventory finance to PUE companies.
    - Provide credit guarantees to local financiers to implement rural consumer financing schemes.
    - Provide equity investment to support business expansion without the burden of interest payments.

5. **Donors should focus grant support on non-revenue-generating activities critical to the PUE industry's success. They should:**
    - Fund needs assessment activities to determine PUE potential at prospective sites.
    - Create a coordination platform for funders to understand and invest in PUE opportunities across various sectors.
    - Create a knowledge platform to share insights from implementing development interventions in Nigeria and scale ecosystem approach to other countries.
    - Support an industry association for PUE companies to share knowledge, build partnerships, and coordinate advocacy.
    - Continue funding early-stage projects without commercial viability.

The EAP's experience has demonstrated PUE's potential to sustain energy access investments, reduce reliance on polluting fossil fuels, increase farmer incomes, and create jobs in rural economies. Additionally, the program confirmed the effectiveness of an ecosystem approach for developing sustainable business models that provide PUEs to those who need them most. Expanding the EAP approach regionally could bring the benefits of PUEs to millions in communities urgently needing economic development.

1. Introduction

Four in 10 Nigerians live without access to electricity today, leaving households and businesses in the dark or reliant on costly fossil fuel–powered generators.[2] Solar minigrids are the lowest-cost option to bring reliable, renewable electricity to millions living in communities far from the centralized grid network or where existing grid reliability is extremely low.[3]

In the past decade, the Nigerian Rural Electrification Agency and a growing number of private energy developers have grown the sector to roughly 170 active minigrids. The World Bank–sponsored Nigerian Electrification Project has subsidized a majority of these, deploying 11 megawatts of solar capacity and connecting more than 60,000 people to electricity services.[4]

However, data from a subset of 11 rural minigrids shows that these systems are imperiled by low electricity consumption by their customers, who spend an average of less than US$2 per month on power. This level of monthly consumption — around the 9 kilowatt-hours (kWh) it takes to run a 60-watt lightbulb for five hours each day — is too low to support income-generating activities that link electricity access to improved lives.[iii] In turn, the sales revenues to the rural utility are too low to maintain infrastructure and service quality.

Productive uses of energy (PUEs) such as milling, cold storage, electric mobility, and many others use electricity to make money. In Nigeria, where agriculture is the mainstay of rural economies, electrifying agricultural activities can boost farmers' productivity and incomes while driving electricity sales and strengthening the local utility. Previous work by RMI identified several high-potential uses of minigrid electricity across 12 value chains, from rice milling to cassava grating to electrifying rural two-wheelers.[5] These PUEs are primed to reduce energy costs, increase the value of local agricultural products, and catalyze more investment in minigrids and agribusinesses in a cycle of compounding rural economic growth.

Yet, electricity and agriculture partners often miss these opportunities while working in silos:

- Minigrid developers sometimes lack knowledge of PUE opportunities in their coverage areas and the financial resources required to build that knowledge and support agricultural productive uses.
- Agricultural machinery and service providers are unaware of the potential market for their offerings in minigrid communities and the various business models that can deliver them to market. They are also often too cash-strapped and short-staffed to expand and maintain operations in far-flung rural areas.

The challenges faced by minigrid developers and PUE companies mean promising energy-agriculture solutions that can attract investment to rural economies never materialize.

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iii A "modern energy minimum" of 1,000 kWh/year (83 kWh/month) is tightly correlated with US$2,500/year, roughly the midpoint for low-middle-income status (Energy for Growth Hub, 2021, **https://energyforgrowth.org/article/modern-energy-minimum/**).

The EAP addressed these challenges by bringing energy and agriculture partners together, finding opportunities of shared interest, and working to refine and pilot first-of-their-kind PUE projects.[iv]

The EAP's Agriculture-Energy Innovation Accelerator paired Nigerian energy and agriculture companies to deploy 52 units of PUE equipment across five value chains in 17 minigrid communities (see Exhibit 1). Over the course of three years, companies formed partnerships and tested the viability of new business models in cold storage, electric mobility (e-mobility), electric motor retrofits, oil palm processing, and rice milling. **Box 1** (page 17) explains further how the accelerator worked with partners to design and test these business models.

The Energizing Agriculture Programme (EAP) helped Nigerian energy and agriculture partners overcome these challenges and demonstrate the promise of PUE through on-ground pilots. This report describes their results.

Exhibit 1 Map showing minigrid communities where the EAP Agriculture-Energy Innovation Accelerator deployed PUE equipment

RMI Graphic. Source: EAP pilot data

iv The EAP was co-led by the Rural Electrification Agency and RMI, with support by the Global Energy Alliance for People and Planet. Our website includes videos, articles, and more about our partners at https://energizingagricultureprogramme.org/.

Participants at the EAP's 2023 Scaling Bootcamp in Abuja. Photo credit: TNF Media

These partners also collected pilot data on how their equipment used electricity and how their business models functioned in practice. This data and the real-world experiences are the foundation of the insights presented in this report:

- **Section 1**, the introduction, discusses the challenges minigrids face today and the need for PUE to achieve commercial sustainability. The section also provides an overview of the accelerator's approach to pilot project design and implementation, and the methodology used for the analysis presented in this report.

- **Section 2** analyzes the technical and economic performance of existing minigrids unsupported by PUE loads.

- **Section 3** discusses findings from the pilot projects implemented, including economic analysis of the viability of PUE business models and lessons learned. The section also describes different support levers needed to unlock a pathway to scale for the business models.

- **Section 4** presents analyses conducted using HOMER modeling software on the impact of different PUE loads on optimal minigrid design and economics.

- **Section 5** provides a clear roadmap of steps to ensure all rural electrification projects are developed to effectively stimulate agricultural productive use, including specific recommendations for different stakeholders in the agriculture-energy ecosystem.

Box 1

The accelerator provided a supportive environment for energy and agriculture companies to test new concepts.

How energy and agriculture companies, supported by EAP technical assistance and grant funding for implementation costs, collaborated to deliver affordable agricultural equipment to rural entrepreneurs.

1 Site identification

RMI and minigrid developers worked together to identify electrified farming communities interested in adopting agricultural machinery.

2 Partnership building

RMI facilitated the matchmaking of minigrid developers, PUE equipment suppliers, and other organizations with a shared vision to electrify rural agricultural businesses. The partners signed MOUs to form accelerator teams.

3 Business model design

The accelerator team members held collaborative working sessions to design scalable business models that boosted rural customers' access to affordable agricultural equipment, while also giving them opportunities for business expansion.

4 Processor selection

The team surveyed farmers, crop processors, and agricultural extension agents in 17 minigrid sites to determine their capacity to participate in the business model designed by the accelerator.

5 Pilot operation

The PUE companies delivered equipment to selected entrepreneurs and trained them on operation and basic maintenance. The minigrid developers installed dedicated energy meters to monitor equipment usage.

6 Monitoring and evaluation

RMI built analytical tools to assess the commercial viability of the business models tested and their potential impact on minigrid economics.

1.1 Methodology

RMI worked with developers and PUE companies to collect data on minigrid and PUE equipment performance throughout the accelerator implementation period. We then determined the potential impact of agricultural loads on minigrid economics through several analytical steps. First, data cleaning methods were used to synthesize large amounts of energy demand and sales data collected from pilot projects to understand the consumption patterns of customers and communities. Second, an energy systems optimization tool was used to determine the optimal system design to meet combinations of community and PUE loads. Finally, financial models were developed to assess the profitability of PUE business models tested by the accelerator and minigrid infrastructure under various scenarios. The methodology is illustrated in Exhibit 2, and each step is discussed below.

Exhibit 2 **Methodology for the analysis presented in this report**

RMI Graphic. Source: EAP analysis

Data collection. We worked with accelerator team members to collect data to inform the analyses in this study. The data collected includes:

- **Energy consumption:** Minigrid developers provided access to their meter data through Odyssey Energy Solutions' platform. We then worked with Odyssey to collate hourly electricity consumption data at equipment and community levels across all sites where PUE equipment was deployed.
- **Business model performance:** The commercial anchors of the business model deployed monthly questionnaires to EAP beneficiaries to document how their equipment was being used and all costs associated with running the business.
- **Partner and customer satisfaction:** Qualitative data on customer satisfaction was gathered through field agents. Additionally, we facilitated biweekly sessions for accelerator team members to discuss their experiences participating in the EAP.

Data processing. The analysis presented in this report is based on smart meter data collected from EAP pilot sites and equipment. After receiving permission from the minigrid operators, the data was aggregated by Odyssey Energy Solutions and shared with RMI. R scripts were used to clean 365,000 hours of time-stamped electricity data on minigrid systems and the PUE equipment they powered. Outliers created by known smart meter synchronization issues were removed. Load profiles were created by analyzing load patterns for each hour of the day for all minigrid systems and PUE equipment. These profiles were used in subsequent cash flow analysis and HOMER optimization.

Minigrid system design and optimization. The load profiles obtained in the data processing step were put into HOMER software to determine the minigrid system designs that satisfy expected community loads, with and without PUE. HOMER is a modeling tool that determines the least-cost mix of distributed energy resources to meet a specific load. It does this by simulating all possible system configurations and hourly electricity dispatch patterns and calculating life-cycle costs (capital and operating costs) associated with each configuration. Appendix A explains how HOMER was parameterized for the analysis.

PUE cash flow analysis. Three cash flow model templates were built to assess the profitability of the PUE business models tested: one for aggregator and offtake-based models (cold storage), another for lease-to-own models (electric motor retrofits, oil palm processing, and rice milling), and a total cost of ownership (TCO) model for electric mobility. The assumptions made are detailed in Section 3.

Minigrid cash flow analysis. A cash flow model was built to assess the commercial viability of minigrid infrastructure under various scenarios for system component costs, load growth, electricity pricing, and financing. The key outputs from this model were the levelized cost of electricity (LCOE) and tariff needed to deliver a specified return on investment. Other important indicators obtained were the investment's internal rate of return (IRR) and net present value (NPV). The modeling assumptions are provided in Appendix A.

1.2 Macroeconomic Context of Analysis

The accelerator pilot projects began operation at different times between January and October 2023 and have since remained operational. During this period, there has been unprecedented volatility in Nigeria's macroeconomic conditions due to changes to the foreign exchange regime, the removal of petrol and electricity subsidies, and high inflation. For this reason, the economic analyses presented in the subsequent sections quote monetary values in US dollars, with naira (NGN)–denominated costs converted at the exchange rate specified below. The analyses across all agricultural value chains were updated to use the same assumptions outlined in Exhibit 3 to allow for direct comparisons. Nonetheless, it is essential to note that the depreciation of the naira affects the results presented in several ways:

1. Minigrid tariffs in naira terms may be significantly higher than for existing projects, even when US dollar values have decreased.

2. The market value of agricultural outputs will be lower because they are priced in naira, which depreciates faster than inflation.

3. The effect of cost inflation may be indiscernible because of the conversion to US dollars.

Exhibit 3 Macroeconomic indicators used in cash flow analyses

Indicator	Value
US$ to NGN exchange rate	1,483
NGN/US$ depreciation	2% year-over-year
Operations and maintenance cost inflation	5% year-over-year
Diesel price	NGN 1,500/liter
Petrol price	NGN 1,000/liter

RMI Graphic. Source: EAP pilot data; EAP analysis; Central Bank of Nigeria (CBN)

Subsequent sections explore the effects of these macroeconomic assumptions on minigrid economics and PUE business model performance.

2. Economics of Minigrids Today

Drone footage of a minigrid in Gwam, Niger state. Photo credit: TNF Media

To assess the potential impact of PUE loads on minigrid economics, we need to understand the technical and commercial performance of existing minigrids today. Therefore, the EAP investigated the energy use patterns of customers at accelerator locations. Data from 11 minigrids serving nearly 5,000 connections shows that low customer consumption and rapidly devaluating naira-denominated tariffs are challenging system economics today. This section explains the costs and profitability of serving typical rural customers under the status quo. Understanding this provides a baseline for how productive use businesses can be profitable and how combining these productive use loads with typical customer demand can transform the minigrid business case, which we discuss further in Sections 3 and 4.

2.1 Electricity Use at Minigrids

We collected system-level electricity consumption and revenue data from January 2023 to April 2024 for 11 of the 17 sites where the accelerator deployed PUE equipment.[v] These minigrids varied in size from 24 to 200 kilowatt peak (kWp), serving 190–774 customers each. The data was then used to determine each community's average consumption per user (ACPU). Exhibit 4 illustrates how customers utilize minigrid electricity in the sites investigated. The ACPU varied between 0.10 and 0.57 kWh/day across the minigrid sites, averaging 0.27 kWh/customer/day across all customers. This average consumption translates to roughly 100 kWh per customer per year, which is worth just US$17. The average minigrid in the data set had 434 customer connections, putting average annual revenues at just under US$7,000/year.[vi] Energy use was relatively consistent during the daytime, increasing slightly at night to serve additional residential demand.

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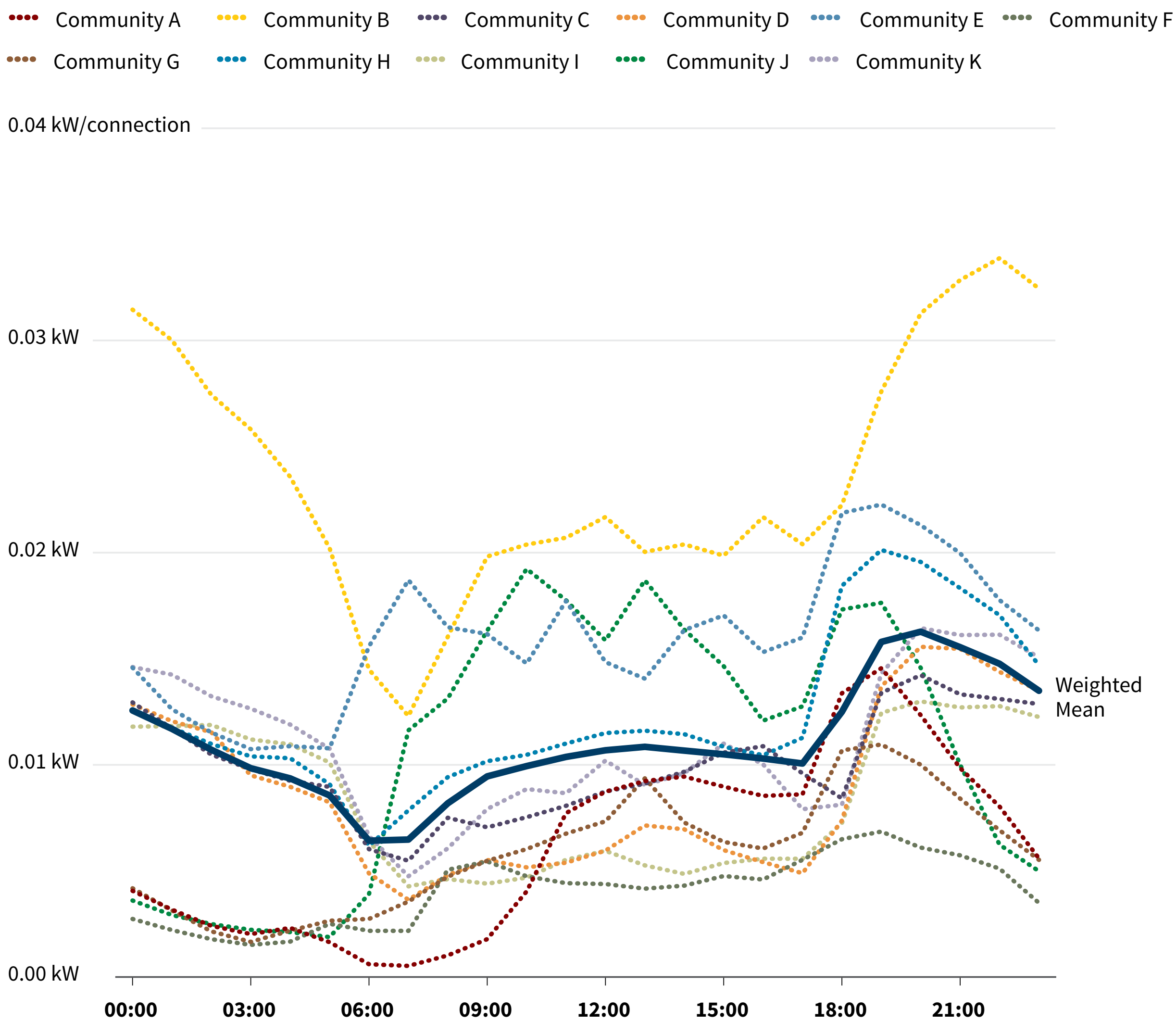
v Identifiable information has been withheld to promote data sharing. Six pilot sites lacked usable smart meter data or developers opted not to share. For one site, data ran from April 2022 to April 2024.

vi Naira tariffs varied from NGN 172 to 285/kWh in the data set, averaging a rate of US$0.17/kWh at the exchange rate used in this analysis (see Box 2). This dollar-equivalent tariff is well below the costs of building and operating a minigrid described below, and shows the challenge of today's macroeconomic market for Nigerian developers.

Exhibit 4 Average hourly electricity consumption per customer across different minigrid communities



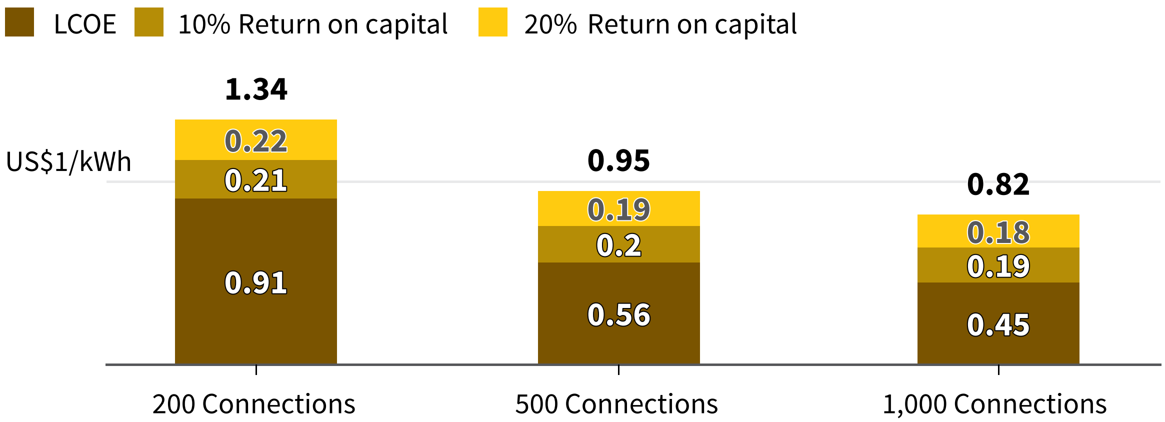
RMI Graphic. Source: EAP analysis

2.2 Affordability of Minigrid Electricity

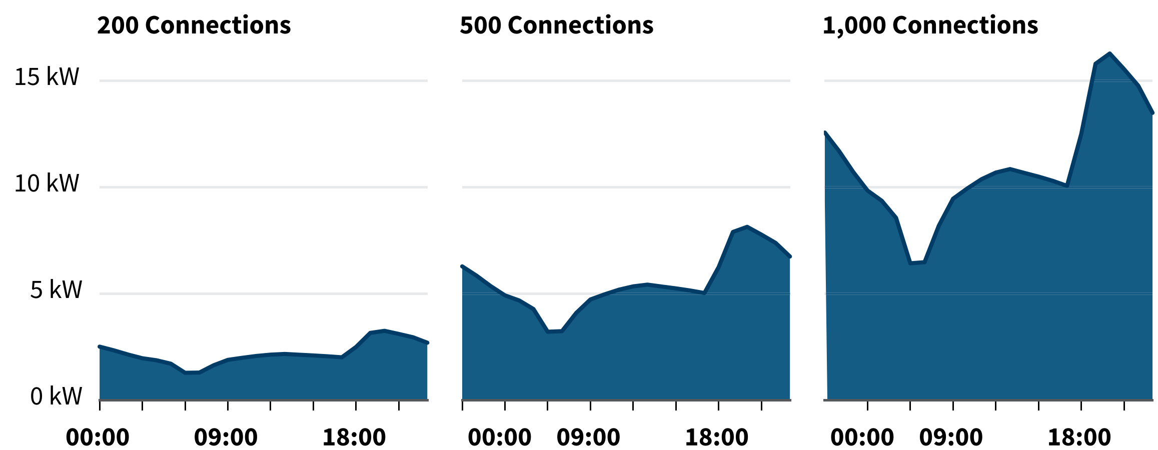
We used HOMER to determine the minigrid system designs that can serve these real customer loads and a cash flow model to calculate their profitability. The modeling assumptions are provided in Appendix A. Exhibit 5 shows the results for minigrids serving 200, 500, and 1,000 non-PUE customers.

Exhibit 5 Optimal minigrid system design for communities serving 200, 500, and 1,000 non-PUE customers obtained using HOMER software

Electricity costs and tariffs for "typical" modeled Nigerian minigrids today



Average daily load profiles for minigrids serving different numbers of non-PUE connections



Number of connections	200	500	1,000
Photovoltaics	21.5 kW	52.9 kW	108 kW
Battery storage	45 kWh	112 kWh	223 kWh
Diesel genset	6.2 kW	16 kW	31 kW
Inverter	4.96 kW	12.7 kW	25.1 kW
Genset production	4,051 kWh	1,565 kWh	8,020 kWh
Initial capex	US$104,378	US$221,527	US$418,145
Initial capex per connection	US$345	US$443	US$418
Annual operations and maintenance cost	US$8,750	US$11,275	US$15,495

RMI Graphic. Source: EAP analysis

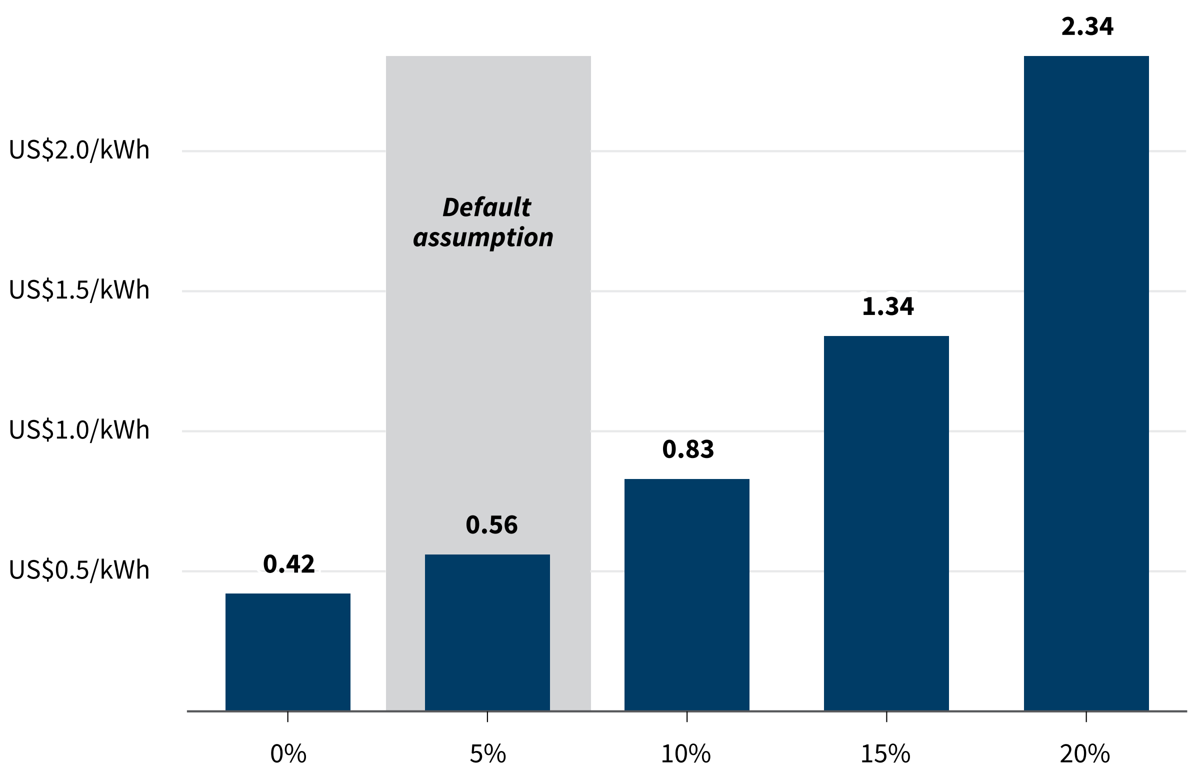
A typical minigrid today, serving about 500 connections, would have an LCOE of US$0.56/kWh and need to charge a tariff of US$0.95/kWh to deliver a 20% return on investment (see Exhibit 5). The smallest minigrid in the EAP portfolio, serving approximately 200 connections, would have an LCOE that is 63% higher. In contrast, a larger system comparable to the largest EAP minigrid site can achieve an LCOE of US$0.45/kWh, 20% lower than the typical minigrid. Thus, the scale of the system built can significantly impact energy affordability. Due to siting and design decisions, rural populations with similar income levels could face different costs to access modern energy services.

As of May 2024, the highest tariff charged at EAP accelerator sites is NGN 285/kWh (US$0.19/kWh) because the minigrids were designed before the naira lost value against the US dollar. At the current exchange rate, tariffs charged would have to triple for a typical minigrid system (with an LCOE of US$0.56/kWh) to break even, highlighting the challenge of achieving commercial viability.

Effects of Macroeconomic Indicators on Minigrid Economics

Nigeria's macroeconomic and policy uncertainties mean that minigrid economics can vary significantly. We investigated the implications of three important indicators on minigrid economics — diesel price, operations and maintenance (O&M) cost inflation, and the NGN/US$ exchange rate — to determine the macroeconomic conditions necessary to realize affordable minigrid electricity. Appendix B further details our findings.

Exhibit 6 Impact of different O&M cost increase rates on minigrid LCOE



RMI Graphic. Source: EAP analysis

Diesel price per liter: Using HOMER, we found that a minigrid optimized to serve the load of 500 typical rural Nigerian customers would have an LCOE of US$0.56/kWh at today's diesel price of US$1.01/liter. This optimized system relies on diesel generators for only 10% of its generation. Consequently, should diesel prices rise, the impact on LCOE would be minimal. We found that a 50% increase in the diesel price would raise LCOE by 4%. However, legacy minigrids designed using cheaper fuel cost assumptions would be significantly more sensitive to diesel prices if they were built with an expectation of cheaper fuel.

Naira to US dollar exchange rate: Similarly, LCOE is relatively uninfluenced by the NGN/US$ exchange rate because most minigrid components are imported and thus priced in US dollars. However, customers, who pay electricity bills in naira, would see their tariffs rise rapidly with the NGN/US$ rate. For example, from July 10, 2023, to July 10, 2024, the NGN/US$ rate rose from 747 to 1,520. A minigrid utility needing a US$0.56/kWh tariff to break even would have had to raise customer tariffs from NGN 418 to 851/kWh in a year to counter the devaluation effect. Raising tariffs, even by small margins, is extremely difficult in rural communities where incomes are low. Customers can also boycott the utility to protest price hikes, as has been observed at some EAP sites. Thus, a devaluing naira would leave developers unable to charge cost-reflective tariffs.

Year-over-year increase in operating costs: A minigrid utility incurs annual costs to maintain the system and pay for staff, security, licenses, insurance, and other local operations. We estimated that the O&M costs for a typical minigrid are US$11,000 in its first year of operation and assumed an annual increase of 5% throughout the minigrid's lifetime. This led to an LCOE of US$0.56/kWh. Should O&M costs increase at twice our assumed rate (e.g., due to higher staff salaries or admin costs), LCOE will similarly double (see Exhibit 6). LCOE is significantly affected by O&M cost inflation, so managing these costs is critical to maintaining minigrid sustainability and electricity affordability.

3. Case Studies

This section discusses five case studies from the EAP accelerator experience deploying PUE equipment: cold storage, electric mobility for farm logistics, electric motor retrofits, oil palm processing, and rice milling. Each case study details the business model tested, the techno-economic performance of the equipment deployed, the lessons learned by the accelerator team members, and pathways to scale each business model.

3.1 CASE STUDY

Cold storage

In September 2022, fishers in Kiguna, a minigrid-connected community in Nasarawa state, lacked access to cold storage to preserve the shelf life of approximately 1,500 kg of fish caught daily.[vii] To prevent wastage, fishers sold fish and other seafood to middlemen and distributors at low prices or preserved them using traditional methods like salting and drying. Fresh or frozen fish can be sold in urban markets for up to 50% more than the local price. The EAP accelerator sought to address Kiguna's fishers' challenges by deploying a minigrid-powered cold storage facility.

Business Model

The Cold Storage Accelerator brought together a cold storage solutions provider, Coldbox Store, and a minigrid developer, Husk Power Systems, to codesign a business model to deliver cooling services to Kiguna's fishers. Supported by the EAP grant, Coldbox installed and operated a 21.6 cubic meter (m^3) capacity cold room at Kiguna under a cooling-as-a-service model targeted toward fishers.

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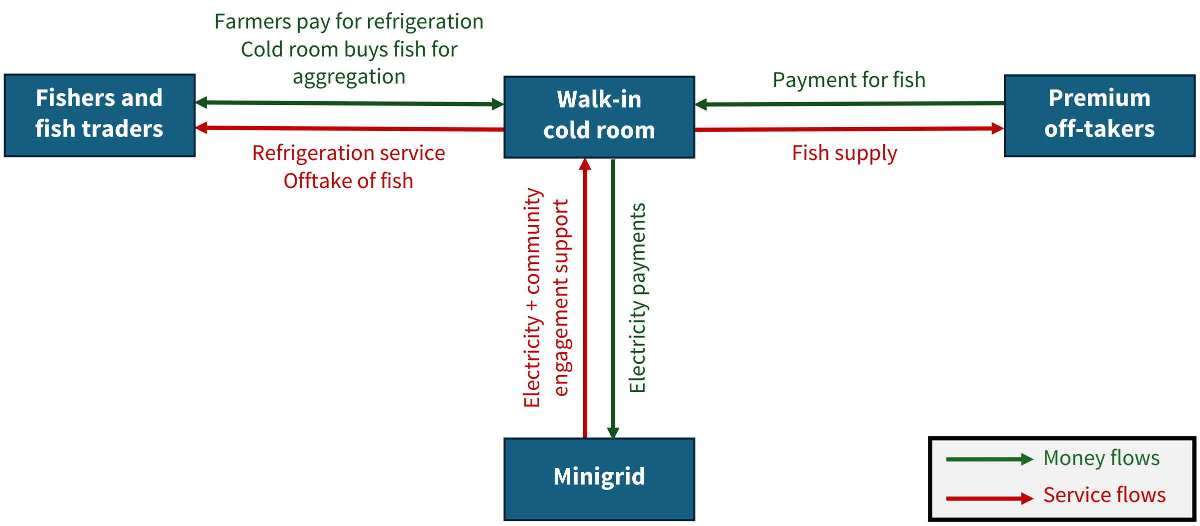
vii Data obtained from site visits by accelerator team members.

Since August 2023, Coldbox has generated revenues for its cold chain solution in two ways: charging fishers a fee to temporarily store their produce and purchasing fish from fishers to resell in higher-value markets. Coldbox collects up to 500 kg of fish weekly and distributes it in towns within a day's drive from Kiguna, including Lafia, Abuja, and Enugu. To boost the inflows of fresh fish into the cold room, Coldbox organized local fish traders into the Kiguna Women Fish Marketers Cooperative Society. These traders were offered training in fish handling and financial literacy, as well as bonuses for meeting monthly targets for collecting fish from communities in the region.

Exhibit 7 illustrates the business model tested by the accelerator and its techno-economic performance until May 2024.

Exhibit 7

Summary of the technical and economic performance of the cold storage solution deployed by the EAP accelerator



Pilot Description		Performance Summary	
Start date	August 2023	**Up-front cost**	US$27,094
Location	Kiguna, Nasarawa state	**Gross revenues**	US$3,890
Minigrid developer	Husk Power Systems	**Power consumption**	5,585 kWh
Equipment provider	Coldbox Store	**Direct jobs created**	29
Equipment operator	Coldbox Store	**Food waste reduction**	1,250 kg
Equipment specifications	3 ton, 21.6 m^3 capacity cold room	**Increased value for fish products**	28%
Cooling service fee	0.7–3.4¢/kg	**Payback period**	7.83 years
Average fish cost price	US$1.48/kg	**10-year IRR**	11%
Average fish sale price	US$1.75/kg	**10-year NPV**	US$35,759
Electricity tariff	US$0.13/kWh	**Average cold room utilization**	8% of total capacity

RMI Graphic. Source: EAP pilot data

Kiguna residents cleaning fish. Photo credit: TNF Media

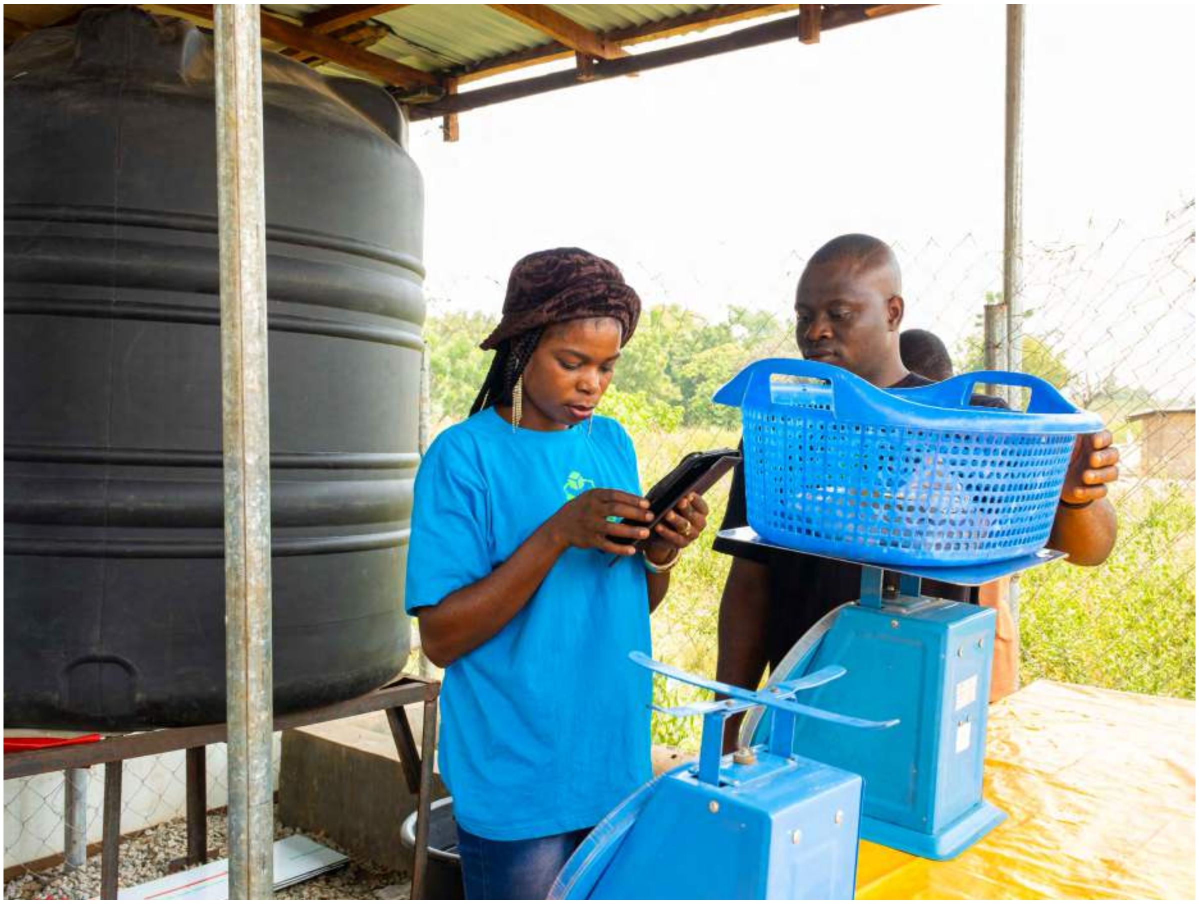
Only about a tenth of the storage capacity was utilized in the early days of cold room operation. The volume of fish stored has since grown steadily, at a rate of 5% month-on-month. The solution has enabled fishers to reduce losses and improve the quality of fish reaching consumers. Coldbox estimates that over 1 ton of fish has been saved from spoilage in the 10 months of pilot operation analyzed here. Additionally, the business model has also improved the sales and profits of fishers, connecting them to higher-value markets and encouraging them to grow their businesses. Coldbox earned 28% more per kilogram of fish collected because of the higher quality and reduced waste.

Cold room utilization began to increase after Coldbox Store invested resources in building trust with the community and recruiting a local agent network to aggregate fish. Nonetheless, the volume of fish stored averaged about 8% of the cold room's capacity by volume. We expect a mature business to have higher utilization rates than observed at Kiguna, so we assessed the potential value creation from such a business under typical commercial terms in Nigeria. A cash flow model evaluated the cold room's profitability using the assumptions outlined in Exhibit 8. Even when using the 30% interest rate typical of financing available in Nigeria, the cold room's business case remains promising. After 10 years of operation, the cold room would have an NPV of US$19,400 and would have contributed US$32,250 in electricity sales to the minigrid developer. Investment in the business is also repaid in less than five years.

Exhibit 8 Commercial business model assumptions for minigrid-powered cold storage

Assumptions		10-Year Indicators	
Minigrid tariff	US$0.10/kWh	**Payback period**	4.5 years
Financing terms	100% debt	**IRR**	15%
Loan interest rate	30%	**NPV**	US$19,433
Maximum storage capacity	12,000 kg/month	**Electricity payments**	US$32,254
Average utilization	45%	**Volume of fish stored**	597 tons

RMI Graphic. Source: EAP analysis



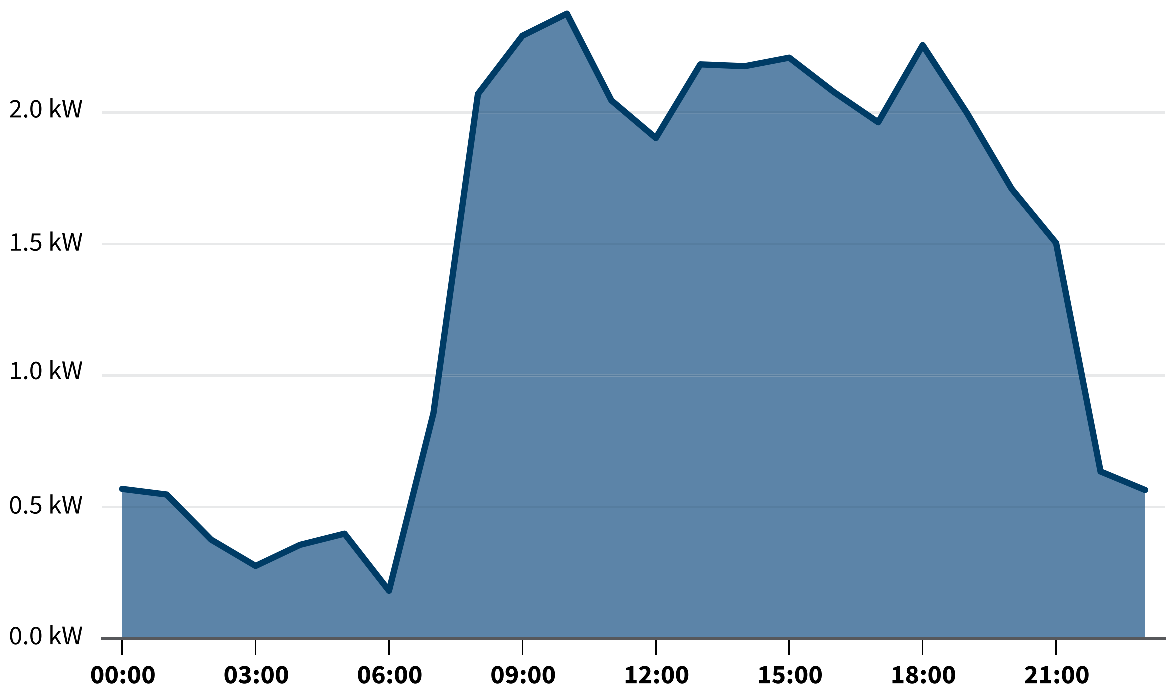
Patricia of Coldbox Store weighing fish and logging transaction before storing in the walk-in cold room in Kiguna. Photo credit: TNF Media

The cold room's profitability greatly depends on the gross margin on fish sold, the volume of fish stored, and the electricity tariff. A gross margin of at least US$0.2/kg of fish is needed for a positive business case (see Appendix C). So, if the price premium offered by off-takers falls below that, the business model is unsustainable. Similarly, the cold room must store at least 3,000 kg of fish monthly to break even. Therefore, for future projects to be viable, they must be located where higher volumes can consistently be aggregated.

Electricity Use by the Cold Room

On average, the cold room consumed 34 kWh daily — nearly 130 times the consumption of a typical rural minigrid customer — and accounted for 25% of minigrid revenues. Cold room electricity consumption was primarily during peak daylight hours, whereas other residential customers used more electricity during nighttime hours for lighting (see Exhibit 9). This was partly because of the reduced availability of the minigrid at night and the incentives offered by the minigrid developer for daytime usage. Consequently, the cold room used low-cost solar power that would have been curtailed otherwise because of a lack of daytime demand from noncommercial customers.

Exhibit 9 Average daily load profile of a walk-in cold room



RMI Graphic. Source: EAP pilot data

Lessons Learned

The accelerator has shown the potential for cold storage solutions to create value for fishers through reduced food wastage, higher incomes, and more jobs. Additionally, they can add significant revenues to minigrids and ensure their sustainability. Scaling such an intervention could be transformational, and the EAP's experience has provided the following learnings to guide cold storage service providers looking to expand operations across the country and beyond:

- **Large walk-in cold rooms are primarily daytime productive use loads, so they provide an opportunity for significant energy sales during low-demand hours.** Cold room electricity consumption occurs during peak solar generation hours when electricity is generated at near-zero marginal cost and demand is low because most residents work on farms outside the community.

- **The unit economics of the business model are promising, but aggregation is critical to profitability.** Coldbox's offtake clients — urban hotels, restaurants, and supermarkets — are eager to buy much more fish than the Kiguna cold room can deliver today. The business model also has healthy unit economics with a 20% gross profit margin and an average gross profit per unit of US$0.27/kg of fish. To ensure profitability and investment payback, the company needed to increase the volume of fish processed in the cold room, which it achieved by incentivizing a local agent network to aggregate fish.

- **Project economics can be improved by downsizing the cold room.** The cold room was expected to store 3,000 kg weekly, but actual volumes were 83% less. A right-sized cold room or chest freezer could reduce up-front costs, although some costs would not decrease linearly with system capacity (civil works, refrigeration units, electrical installation).

- **Cold storage solutions should be designed to be resilient to minigrid downtime, but minigrid reliability is also essential for equipment longevity.** Many minigrids experience reduced availability at night due to high diesel prices and deteriorating batteries. This cold room was designed to blast-freeze products in a very short time. Consequently, it is usually full of frozen fish that stay cold even if temperatures rise slightly above freezing during an outage. The cold room is also able to recover when power comes back online. These design features ensure the freshness of products despite regular downtime. However, regular cooling and warming cycles reduce the efficiency of the cold room's compressor and contribute to its high energy consumption.

- **Cold rooms should be located near large cities with higher prices and demand for fish products.** There is an opportunity to double margins if products can be sold in the largest urban markets such as Abuja, Enugu, or Lagos. A refrigerated truck will be needed to transport products if the cold room is not close to such markets.

- **Business expansion is only sustainable through efficient on-ground operations and off-taker linkages.** This is an operations-heavy business model, so scaling requires limiting the complexity of operations. This can be achieved by enabling community-run cooperatives to manage cold room operations and building a digital platform to connect cold rooms, thus reducing the draw on the cold storage provider's resources.

Scaling Plans

Coldbox Store plans to replicate the cold storage business model across more sites. It has already built a solar-powered cold room in Enugu state, with grant support from the US African Development Foundation. Additionally, it is building a pipeline of 40 cold rooms nationwide. At the time this report was written, they were in discussions with impact investors to finance this project pipeline.

Kiguna resident in front of cold room facility. Photo credit: TNF Media

3.2 CASE STUDY

Electric mobility for farm logistics

Agricultural extension agents are responsible for disseminating vital knowledge about good agronomic practices, improved crop varieties, and appropriate agrochemicals to smallholder farmers, who contribute more than 80% of the country's agricultural production. However, these agents face a significant challenge: reaching these farmers. Rural communities, where most smallholders reside, often have seasonal roads impassable to cars. The difficult terrain and lack of access to suitable transportation contribute to Nigeria's low extension agent-to-farmer ratio: a single extension agent serves about 7,500 farming households.[6] This limited reach results in reliance on traditional practices among farmers, leading to lower productivity and incomes.

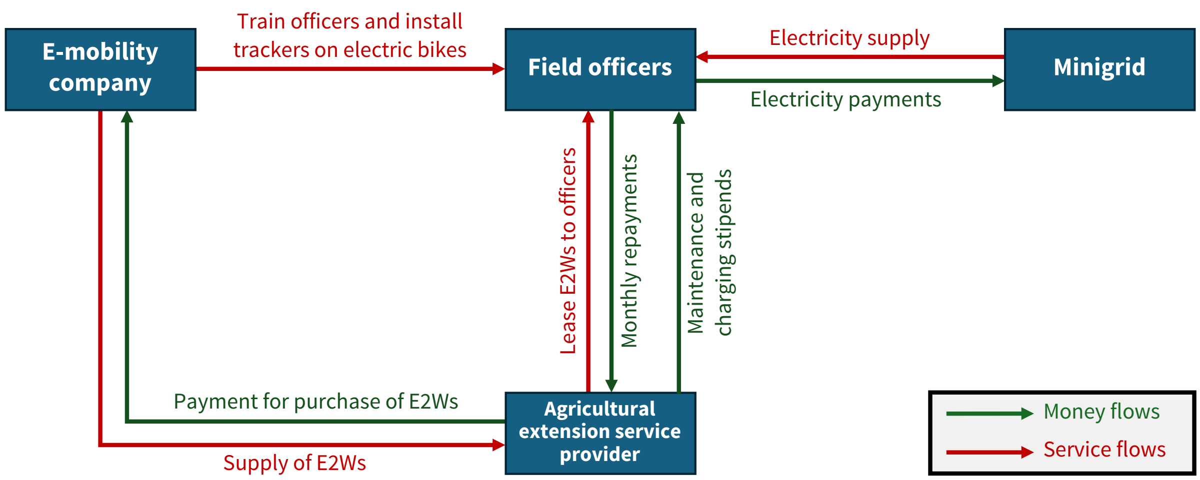
Innovative social enterprises like Babban Gona and One Acre Fund (OAF) are addressing these challenges in the maize value chain. They employ agents and equip them with petrol-powered motorcycles, provided on a lease-to-own basis, along with fuel and maintenance stipends. This approach increases agents' mobility and allows them to reach more farmers effectively. Both enterprises also offer additional support to farmers by facilitating access to inputs and markets for their crops. Consequently, smallholder farmers are empowered through increased productivity and access to reliable markets, ultimately boosting Nigeria's agricultural output. However, since 2023, Nigeria has faced economic crises that have resulted in the removal of petrol subsidies. Overnight, the cost of mobility tripled, leading to burgeoning costs for Babban Gona and OAF.[7]

The Electric Mobility for Farm Logistics Accelerator team sought to address this challenge by replacing expensive and polluting petrol-powered motorcycles (with internal combustion engines [ICEs]) with electric two-wheelers (E2Ws) for agricultural extension agents.

Business Model

The accelerator brought together an e-mobility company selling two-wheelers, MAX NG, two agricultural extension service providers, Babban Gona and OAF, and two minigrid developers, ACOB Lighting Technology Limited and Solmenz Engineering Limited. Funded by the EAP grant, Babban Gona and OAF purchased E2Ws from MAX NG and deployed them to six field officers in their network. They continued providing the officers with stipends for vehicle maintenance, charging costs, and other extension activities. The officers charged the E2Ws at minigrid locations operated by ACOB and Solmenz, paying for electricity on a PAYGO basis. The business model is illustrated in Exhibit 10.

Exhibit 10 Summary of the technical and economic performance of the E2Ws used for farm logistics



Pilot Description		Performance Summary (compared with ICE vehicles)	
Start date	April 3, 2023	**Up-front cost**	US$1,719 (+231%)
Location	Gwam, Niger state Makami, Kaduna state	**Range**	160 km
Minigrid developers	ACOB Lighting Solmenz Engineering	**Efficiency**	0.04 Wh/km (+25%)
E-bike provider	MAX NG	**Battery size**	5.47 kWh
Agriculture extension service providers	Babban Gona OAF	**TCO**	2.16¢/km (−20%)
Electricity tariff	US$0.16/kWh	**Direct jobs created**	7
Petrol cost	US$0.67/liter	**Energy costs savings**	US$316/year (50%–80%)

RMI Graphic. Source: EAP pilot data

The EAP installed trackers on the E2Ws and petrol motorcycles used by agents to determine how the vehicles were operated and maintained. A cash flow model was then developed to calculate the total lifetime cost of owning and operating the vehicle, expressed as US$ per kilometer driven (see Exhibit 11). Despite being three times more expensive to purchase, E2Ws are 20% cheaper to run than petrol

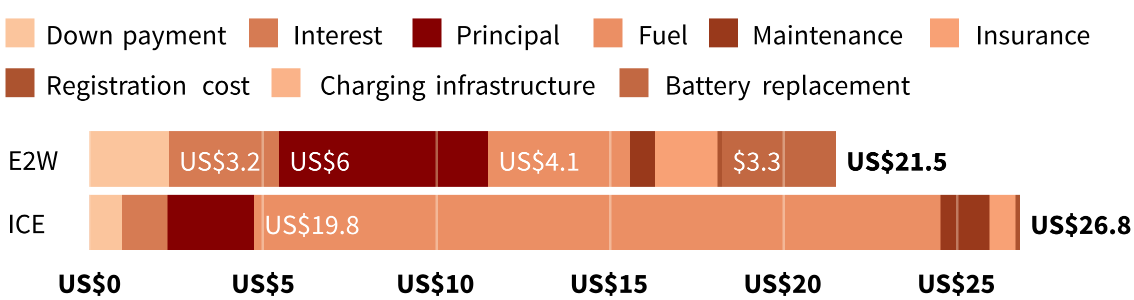
OAF agent driving a MAX NG E2W in Gwam, Niger state. Photo credit: TNF Media

motorcycle over12 years.[viii] Specifically, E2Ws cost US$21.5 per 1,000 km traveled compared to US$26.8 for ICE bikes, highlighting E2Ws' cost-effectiveness in rural agricultural settings today. Therefore, transitioning a bike fleet from petrol to EVs has economic benefits, in addition to the environmental benefits of reducing pollution and fossil fuel consumption.

The competitiveness of E2Ws significantly depends on affordable electricity for charging. We conducted a sensitivity analysis to determine how vehicle and energy costs affect the TCO (see Appendix D). Using the pilot's capital costs and vehicle utilization assumptions, E2Ws and petrol motorcycles reach cost parity at US$0.40/kWh. The analysis in Section 2 shows that the LCOE of a typical 500-connection minigrid built today is US$0.56/kWh. Consequently, a combination of up-front electric vehicle (EV) cost reductions, efficiency improvements, and special tariffs for EV charging can help electric mobility solutions to continue to be attractive.[8]

Exhibit 11 TCO of different two-wheelers for farm logistics

Cost per 1,000 kilometers covered



RMI Graphic. Source: EAP pilot data

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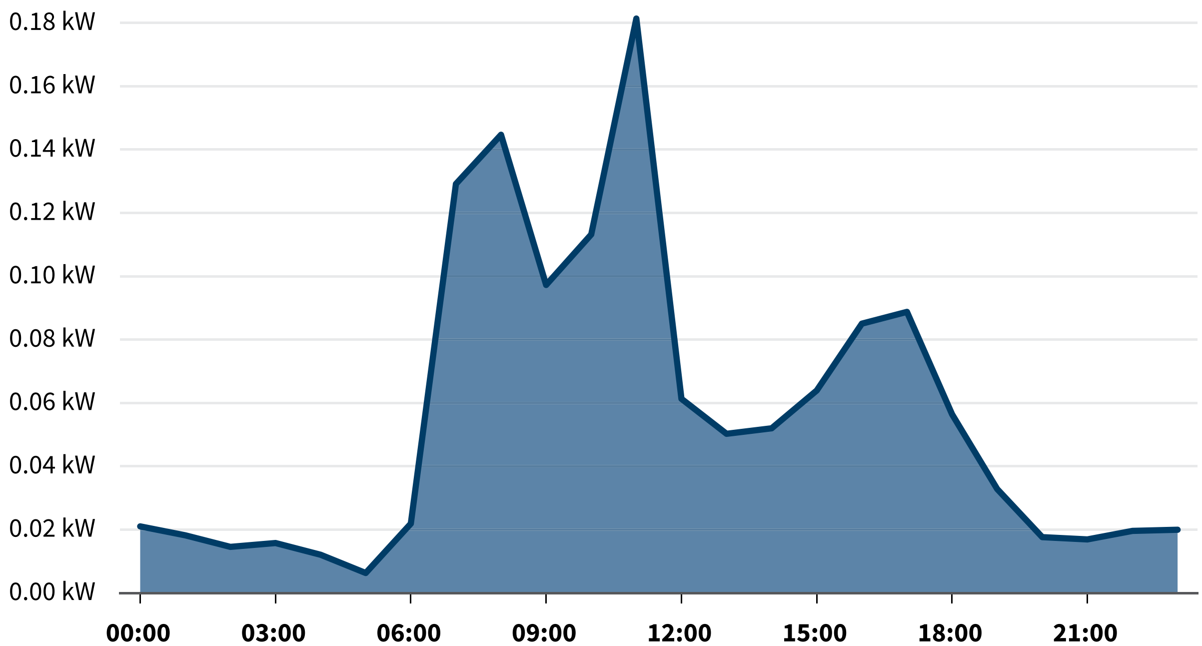
viii Twelve years is the typical lifetime of an ICE two-wheeler. Note that the E2W requires battery replacements every seven years, which are accounted for in the TCO calculation.

Electricity Use by Electric Two-Wheelers

On average, the E2Ws deployed by the accelerator consumed 1.3 kWh/day, equivalent to five times the consumption of an average minigrid customer. Bike charging primarily occurred during the daytime when solar generation was abundant, peaking at 11 a.m. (see Exhibit 12). Thus, E2Ws helped boost minigrid revenues by utilizing surplus availability during the day that would otherwise have been curtailed and unbilled.

Exhibit 12 Average daily load profile for an E2W deployed by the EAP accelerator



RMI Graphic. Source: EAP pilot data

Lessons Learned

- **Cost competitiveness of E2Ws significantly depends on vehicle usage.** EVs cost less per mile to operate compared to ICE alternatives, and they must be driven enough over their lifetimes to compensate for higher up-front costs. Taxi drivers in a previous MAX E2W pilot covered just 10 km daily, which was too low to offer significant TCO savings.[9] The field extension officers in the EAP pilot covered 17 km–54 km daily, contributing to the 20% TCO advantage presented in Exhibit 11.

- **Optimizing battery size and charger placement to fit the EV driver use case can further reduce costs of electrifying fleets.** With a range of about 160 km on a single charge, the vehicles are well-suited for field officers who typically cover around 45 km daily. As long as reliable charging is available when drivers need it, downsizing the batteries to fit daily demands by field officers would help reduce costs, so long as there is sufficient capacity to keep range anxiety in check.

- **High up-front cost remains the biggest barrier to E2W adoption. A maturing EV market will need to add a range of E2Ws at competitive costs as well as accessible vehicle financing.** E2Ws are currently priced at least two times higher than traditional ICE bikes. Accessible financing for consumers and fleets can help overcome the up-front cost hurdle. Further, many suppliers on the market today are offering a wider range of E2W styles, battery sizes, and price points. This is a significant improvement over the landscape at the outset of the EAP pilot, when the only rural-ready vehicle on the market was the MAX M3, a higher-end model. A pilot beginning today would already have more options, including new models from MAX. Growing competition and market offerings will only further help consumers and fleets find the right vehicles for their needs and budgets. Organizations such as Bob Eco, Spiro Nigeria, and Siltech are examples of new entrants currently delivering E2Ws and after-sales support to their customers.

- **A viable business model for E2Ws requires O&M services to be close to customers.** Most E2Ws deployed required minor repairs within six months of operation, including rectifying problems with voltage regulators for the dashboard display and cracked plastic throttle handles. The current model relies on the original equipment manufacturer to supply after-sales services and spare parts. However, MAX has no rural Nigerian footprint and a limited spare parts inventory in Nigeria. Additionally, OAF and Babban Gona had to remotely coordinate with MAX staff to identify parts needs, get them shipped, and guide field officers to install them. Consequently, a simple repair took at least two months. A faster-response vehicle maintenance model is needed for OAF and Babban Gona's plans to add 100 EVs to their fleets.

Scaling Plans

Based on their experience with the EAP pilot EVs, OAF and Babban Gona aspire to increase the number of E2Ws in their fleets to 100. Both organizations worked on this scaling concept during the 2023 Scaling Bootcamp, making significant strides toward clarifying a business model that can solve pain points from the pilot project, including collaborating with a technical service partner who can provide decentralized maintenance support services and improve response times through local service centers and technicians.[ix] They are also planning where additional EVs and charging stations could be deployed.

Additionally, RMI is supporting Babban Gona and Konexa, a minigrid developer, in planning a coordinated rollout of 100 E2Ws and minigrid-powered charging stations.

Babban Gona and Konexa representatives brainstorming charging station models during a working session at the July 2023 EAP Scaling Bootcamp. Photo credit: TNF Media

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ix The 2023 Scaling Bootcamp was a convening of EAP partners to discuss scaling pathways for the PUE business models tested through the accelerator.

3.3 CASE STUDY

Electric motor retrofits

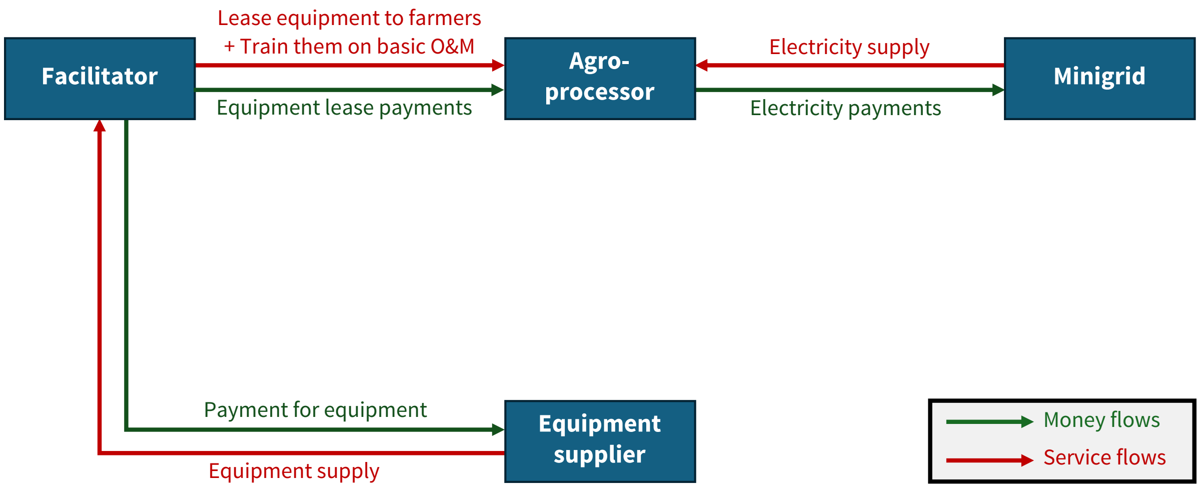
Smallholder farmers are the backbone of agricultural production in Nigeria. Yet, they cannot maximize value creation from their crops because rural communities lack processing capacity. Low incomes and limited access to financing prevent them from acquiring modern equipment, so many farmers rely on inefficient and expensive fossil fuel–dependent processing methods. Infrastructure deficits further worsen the situation. The lack of reliable and affordable energy and poor all-season roads hinder farmers' competitiveness. Consequently, the economic transformation potential of agro-processing remains unrealized.

The Motor Retrofits Accelerator team sought to help rural farmers affordably transition from fossil fuel–powered equipment to electric, energy-efficient, durable, rural-ready alternatives. The accelerator deployed seven wet grinders and two hammer mills to processors in Niger state. The hammer mills were used to process staple grains into flour while the wet grinders process soaked grains into a paste.

Business Model

The accelerator brought together a minigrid developer, Prado Power; a PUE equipment retailer, Farm Warehouse; and rural processors to codesign and test a business model for retrofitting existing equipment with electric motors. Farm Warehouse retrofitted processors' existing machines by swapping their diesel and petrol prime movers with an electric replacement, leaving the rest of their machines in place. It then trained the processors on using and maintaining the equipment. Prado Power supplied reliable energy to power the equipment, while the processors paid for the energy consumed and made monthly repayments directly to Farm Warehouse. The business model is illustrated in Exhibit 13.

Exhibit 13 Summary of the technical and commercial performance of the business model tested by the Motor Retrofits accelerator



Pilot Description		Performance Summary	
Start date	December 10, 2022	**Up-front cost**	**Hammer mill:** US$1,279 **Wet grinder:** US$710
Location	Mai Jaki, Niger state Lafian Kpada, Niger state Aninigi, Niger state	**Energy cost savings**	**Hammer mill:** US$4.2/ton (−44%) **Wet grinder:** US$15.5/ton (−82%)
Equipment specifications	**Hammer mill:** 5.5 kW **Wet grinders:** 3 kW	**Processing efficiency**	**Hammer mill:** 122 kg/h (+106%) **Wet grinder:** 57.8 kg/h (+75%)
Minigrid developer	Prado Power	**Energy efficiency**	**Hammer mill:** 39.1 kWh/ton **Wet grinder:** 25.7 kWh/ton
Equipment provider	Farm Warehouse	**Crops processed**	**Hammer mill:** 6.9 tons **Wet grinder:** 72.5 tons
Beneficiaries	9 (6 women, 3 men)	**Power consumption**	2,285 kWh
Processing fee	**Hammer mill:** US$0.014/kg **Wet grinder:** US$0.2/kg	**Direct jobs created**	17

RMI Graphic. Source: EAP pilot data

Petrol-powered wet grinder in Aninigi, Niger state. Photo credit: TNF Media

Although retrofitting equipment boosted processing efficiency by up to 106% and reduced costs by 44%–82%, retrofitting was challenging because the old machines varied significantly and required bespoke, labor-intensive retrofits. Additionally, when retrofitted machines worked differently than the oversized fossil-fueled engines previously in use, some processors unsuccessfully tampered with retrofitted machines and required more follow-up visits for repairs. For these reasons, Farm Warehouse pivoted from retrofitting existing machines with electric motors to outright replacements.

A cash flow model was used to determine the profitability of this adapted business model under typical commercial terms and two sales modalities: buy-and-sell (BnS) and fee-for-service (FFS). In the BnS model, the processor purchases grains from farmers, mills or grinds them, and sells the flour or paste produced for a profit. In the FFS model, the processor charges customers a fee for using the equipment to mill their crops. It was assumed that the processor makes a down payment equivalent to 25% of the equipment cost and then repays the remainder over 12 months. The results show that a hammer mill is more profitable to run under a BnS model than an FFS model because the volumes of guinea corn processed and service fees charged are too low (see Exhibit 14). Currently, hammer mill operators mill an average of 59 kg/day and charge US$1.4 per 100 kg of grain processed. To achieve a payback period of less than three years, the mill must process more than 242 kg/day, or triple service fees to US$4.2 per 100 kg.

In contrast, the gross margin between guinea corn and corn flour prices makes the BnS model very profitable. In May 2024, a 50 kg bag of guinea corn retailed for US$9, while a same-sized bag of flour sold for US$15, resulting in a gross margin of US$6 for every bag processed. Entrepreneurs processing 59 kg daily (approximately one bag) can repay their up-front investment in six months. Additionally, the revenues from selling flour are much higher than the costs, resulting in a high IRR of 22%.

Exhibit 14 Economics of a hammer mill and wet grinder under different sales modalities

Assumptions		3-year indicators	Hammer mill		Wet grinder	
			FFS	BnS	FFS	BnS
Down payment	25% of cost	**Payback period**	Not achieved	0.50 years	0.17 years	5.00 years
Financing terms	100% equity	**IRR**	Not achieved	21.6%	85.1%	−1.4%
Minigrid tariff	US$0.13/kWh	**NPV**	−US$1,261	US$2,510	US$4,732	US$201
Length of lease	12 months	**Electricity sales**	US$324	US$324	US$259	US$259

RMI Graphic. Source: EAP analysis

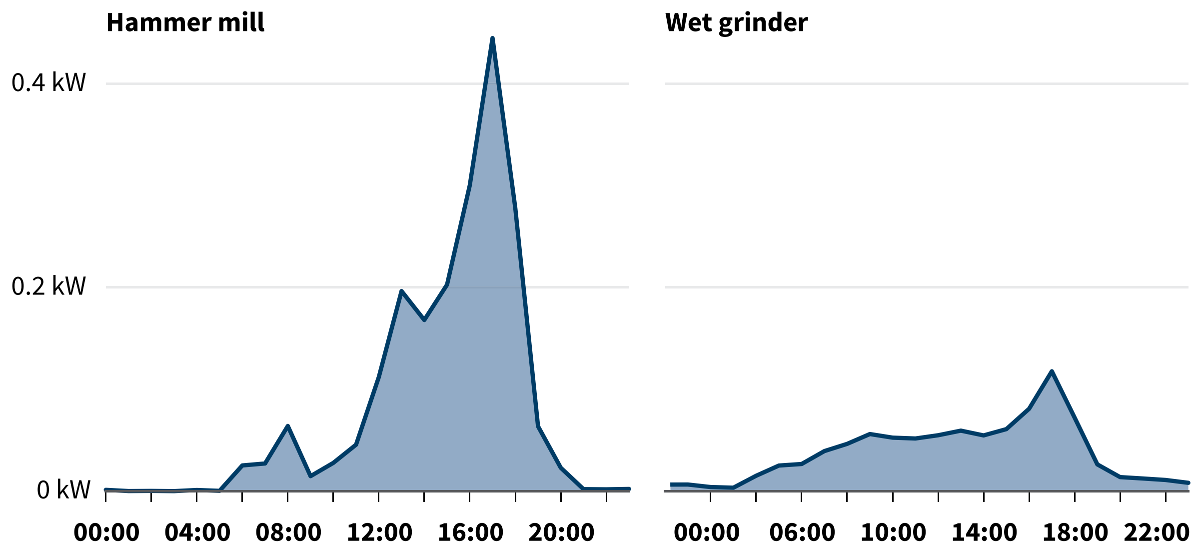
Wet grinders have positive economics under the FFS modality, whereas the return on investment is slightly negative under the BnS modality. Processors grinding 69 kg/day of soybeans can repay their investment in two months and achieve an 85% IRR through FFS sales. Under a BnS model, this would take five years. For a BnS business to achieve a payback of less than three years, the price of bean paste must be higher than US$158/ton. Soyabeans currently cost $128/ton, so a price margin of greater than 24% is needed for BnS sales for the desired payback period.

Electricity Use by Hammer Mills and Wet Grinders

Of the two hammer mills, only one was used consistently for a period of time (from May to July 2024). Smart meter data collected from the beneficiaries in Lafian Kpada, Niger state, showed that the equipment was only consistently operated in March 2024, although installation occurred in December 2022. The reasons for the lack of consistent use are varied: tampering-induced breakdowns described above, challenges with minigrid connections for larger motors, interest in other value chains, among others. The data shown in Exhibit 15 only considers the functional hammer mill.

The hammer mill and wet grinders contributed 2 kWh/day and 0.9 kWh/day, respectively, to the minigrid. The hammer mill was primarily in operation during afternoon hours, peaking at 5 p.m. Although wet grinder operation was steady during daytime hours, it also only peaked at 5 p.m. when solar availability was greatly reduced (see Exhibit 15). Evening loads are typically met by the minigrid's battery storage or diesel genset, which have higher marginal costs. So, there is a need to incentivize processors to shift operations earlier in the day to avoid peak residential demand hours.

Exhibit 15 Average daily load profiles of the hammer mills and wet grinders deployed by the accelerator



RMI Graphic. Source: EAP pilot data

Lessons Learned

- **Despite saving processors money compared to fossil fuel engines, motor retrofits leave too much room for error in rural contexts.** Retrofitting equipment proved challenging for various reasons, including the age of existing equipment, processors' perceptions of the changes, challenges in maintaining consistent quality standards across diverse machines, and processors' habits of self-repair. Even when core machine components were untouched, follow-up visits revealed tampering with the retrofitted machines, which operated differently from the petrol or diesel incumbents. Consequently, Farm Warehouse pivoted to a full machine replacement approach, selling new, energy-efficient electric equipment to processors using petrol machines.

- **Processors accustomed to tinkering with their equipment made modifications that had unintended consequences.** Unlike fossil fuel–powered machines, electric motors connect to a grid, not a fuel tank. Tampering resulted in removed soft starters, changed pulleys, burnt-out motors, and significant grid stability problems.

- **The machine replacement model is more readily scalable than retrofits.** Farm Warehouse provided 24 customers previously shortlisted for retrofits with new equipment.[x] Although the up-front costs of replacing entire machines were higher than motor swaps, introducing new grinders and mills mitigated issues related to tampering. It also decreased the need for follow-up repairs on aging equipment. The equipment, which passed quality assurance protocols to qualify for CLASP's Productive Use Appliance Financing Facility (PUAFF), has proven more reliable and raised customer satisfaction rates.[10]

x These included EAP accelerator and PUAFF sites.

- **Revenues from machine replacements were up to three times the spend on electricity and equipment repayments.** In Aninigi community, a typical wet grinder customer made US$45 monthly, significantly higher than the US$15 spent on energy and equipment repayments. Customers were therefore deriving significant value from new machines.

- **Even with PAYGO models, women could not afford the initial down payment, so the up-front cost had to be removed.** Farm Warehouse initially provided retrofits after beneficiaries made a down payment. However, women could still not afford this up-front cost, leading to the PAYGO model being altered to have no down payment.

Scaling Plans

Farm Warehouse has ambitious plans to deploy nearly 500 additional units of PUE equipment by July 2025. The company's participation in CLASP's PUAFF has boosted deployments significantly, supporting 29 additional sales of freezers, small rice mills, and hammer mills to date. Farm Warehouse's participation in this initiative was due to an introduction from the EAP. Furthermore, during the 2023 Scaling Bootcamp, Farm Warehouse deepened discussions with developers Husk Power and Prado Power, ultimately creating a long-term vision to deploy 3,000 productive use appliances.

Farm Warehouse is engaging with CLASP to increase access to the PUAFF subsidy and achieve this vision. It also continuously adds to its project pipeline across minigrid sites; currently, it has 339 customers awaiting hammers mills, rice mills, and freezers. CEO Kuma Mede is also working toward raising the company's first round of start-up financing, aiming to close a US$1 million investment in 2024. The company continues to receive support from the EAP as it scales, including technical coaching on proactive grid planning for PUE loads with partner Prado Power. EAP staff are also helping Kuma Mede refine his fundraising pitch with RMI colleagues at Third Derivative and will facilitate investor introductions.

Female beneficiary operating wet grinder in Aninigi, Niger state. Photo credit: TNF Media

3.4 CASE STUDY

Oil palm processing

In 2022, oil palm farmers in Adebayo had access to three artisanal mills in neighboring communities. These facilities were grossly inefficient. It took at least 10 hours (and sometimes multiple days) to process a ton of fresh fruit bunches (FFB), during which fruit began to go rancid, ultimately reducing the quality of the crude palm oil (CPO) produced. The oil yield was also poor — the mills produced 114 liters of CPO per ton of FFB, 53% lower than the most efficient machines on the market.[xi] Finally, the mills relied on expensive diesel generators and exposed workers to polluting fumes. These challenges are widespread across Nigeria's oil palm value chain.

Nigeria is the fifth largest palm oil producer globally. In 2023, annual production stood at 1.5 million tons, while consumption was 1.87 million tons, resulting in a demand gap of 0.37 million tons satisfied by imports.[11] Smallholder farmers account for 80% of production.[12] Their operations typically have low levels of mechanization, so they rely on manual harvesting and processing techniques that incur high levels of waste and losses across the value chain. Farmers have struggled to mechanize and commercialize palm oil production despite the domestic demand gap and higher retail prices for several reasons:

- Poor access to information leads to the persistence of outdated manual techniques.
- Access to finance is limited because lenders prefer established businesses with already strong revenue streams. Funds available to small entrepreneurs charge exorbitant interest rates with short tenors.
- Unreliable electricity supply from the grid leads to a reliance on diesel generators, thus increasing the cost of production.

Business Model

The EAP Oil Palm Accelerator sought to address these challenges by making modern processing equipment available and affordable to rural farmers and improving their access to markets through partnerships with

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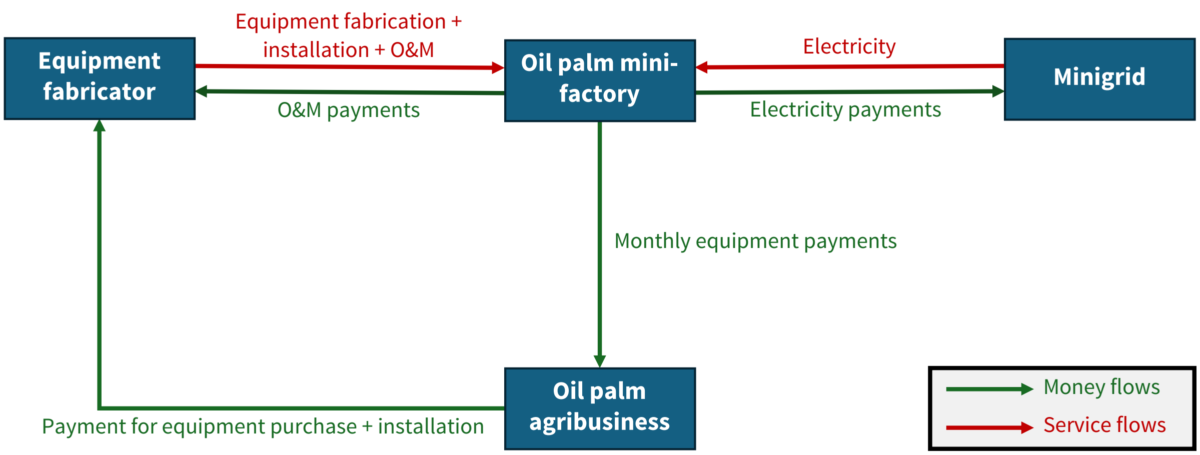
xi According to experiments conducted by the EAP accelerator team.

large agribusinesses. The accelerator brought together a palm kernel oil (PKO) producer, Releaf Nigeria; an equipment fabricator, Muhat Agro-Mech Ltd.; and a rural processor, Lateef Agbaje (the *Baálẹ* of the community[xii]), to codesign a lease-to-own business model for CPO production. Releaf, supported by the EAP grant, financed the fabrication and installation of a small-scale oil palm processing factory in rural Edo state. Muhat, a local agricultural machinery manufacturer in Edo state, designed and fabricated all the equipment. *Baálẹ* then operated the mini-factory, processing his FFB and charging other community members fees for access to the equipment (i.e., an FFS model). *Baálẹ* pays a share of his earnings to Releaf monthly until he pays off the entire up-front cost and asserts ownership of the processing facility. The business model is illustrated in Exhibit 16.

Exhibit 16

Summary of the technical and economic performance of the oil palm mini-factory deployed by the accelerator



Pilot Description		Performance Summary	
Start date	September 29, 2023	**Up-front cost**	US$10,700
Location	Adebayo, Edo state	**Gross revenues**	US$4,370
Minigrid developer	ACOB Lighting	**Power consumption**	2,680 kWh
Equipment provider	Muhat Agro-Mech Ltd.	**Energy cost savings**	$1,500 (−82%)
Agribusiness	Releaf Nigeria Ltd.	**CPO yield**	171 liters/ton (+50%)
Local processor	Baálẹ	**Direct jobs created**	7
Equipment specifications	5 kW thresher 7.5 kW digester screw press 5 kW nut-fiber separator 6 sterilizers and clarifiers	**Payback period**	0.42 years
Processing fee	US$2.02 per drum of FFB	**3-year IRR**	19%

RMI Graphic. Source: EAP pilot data

xii *Baálẹ* is the traditional title of the local chief in some Yoruba-speaking communities in Nigeria. The Yoruba are one of the largest ethnic groups in the country.

Drone footage of artisanal mill in Adebayo community, Edo state. Photo credit: TNF Media

Since commercial operations began in September 2023, the mini-factory has processed 585 tons of palm fruits, producing 101,498 liters of CPO with a market value of US$63,000.[xiii] The facility has added 2,680 kWh of demand to the minigrid, worth US$310 in electricity sales. An artisanal mill would have produced only 67,000 liters from the same amount of fruits, incurring diesel costs of US$1,840. **Thus, switching to electric equipment has resulted in a 50% increase in CPO yields and an 82% reduction in energy costs.**

A cash flow model was used to assess the profitability of this business model without any grant funding and using typical Nigerian commercial financing terms. Exhibits 17 and 18 detail the commercial assumptions and results of the analysis for two sales modalities: BnS and FFS. Our results show that an FFS business is significantly more profitable than the BnS alternative at today's commodity prices. Even with expensive financing, the processor can recover the up-front investment in just over a year and deliver an 8% return on their capital in three years. In contrast, a BnS business will lose US$2,800 in the same period. The BnS business underperforms because the FFB input costs have increased faster than CPO market prices. In contrast, the service fees for using the mini-factory tripled during the pilot operation period. The oil palm value chain shows how macroeconomic turbulence unequally impacts the cost of agricultural commodities and services and, in the process, favors certain business models over others. Consumers' unwillingness to pay more for CPO compared to processing fees meant the FFS model was more viable.

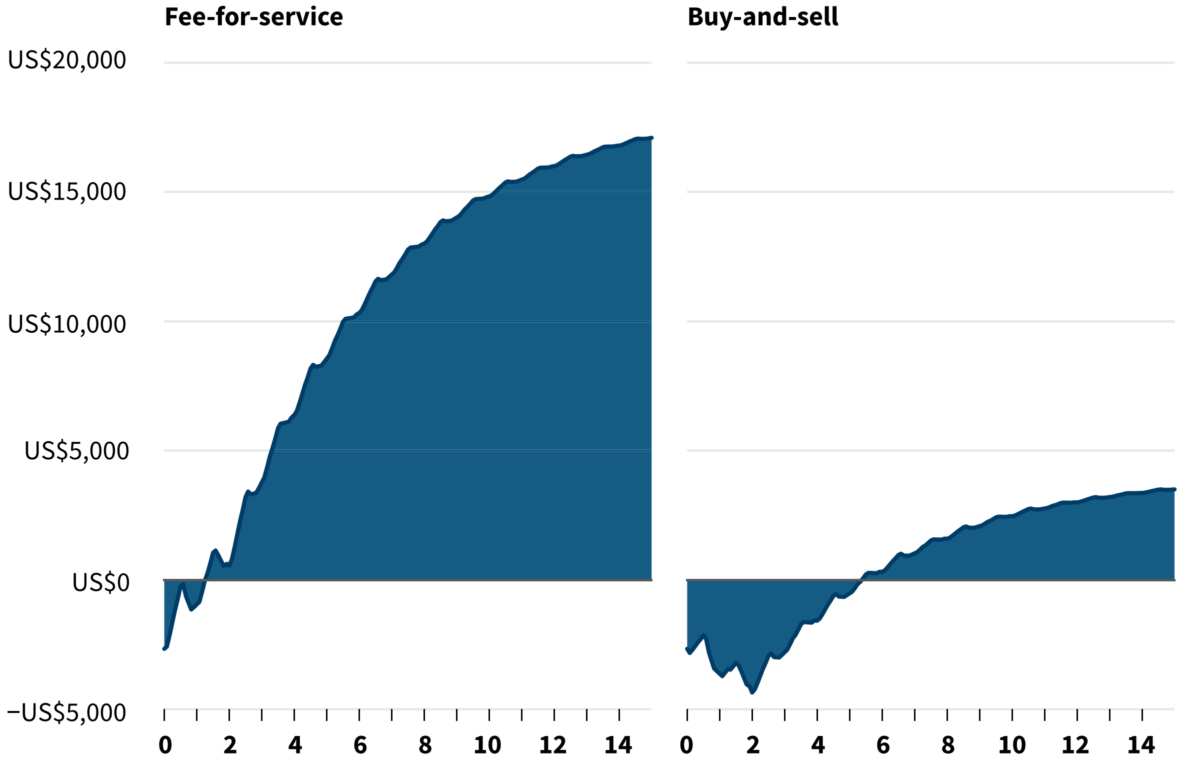
Exhibit 17 Commercial business model assumptions for oil palm processing

Assumptions		3-Year Indicators	Fee-for-Service	Buy-and-Sell
Down payment	25% of cost	**Payback period**	1.33 years	5.42 years
Financing terms	75% debt	**IRR**	8.1%	−3.5%
Loan interest rate	30%	**NPV**	US$3,770	−US$2,800
Length of lease	24 months	**Electricity sales**	US$1,550	US$1,550

RMI Graphic. Source: EAP analysis

xiii Numbers updated on June 1, 2024.

Exhibit 18 **Cumulative discounted cash flow for the oil palm mini-factory over 15 years**



RMI Graphic. Source: EAP analysis

Appendix E details how key business model assumptions affect the profitability of an oil palm mini-factory. The BnS model only becomes more profitable than FFS when the offtake price of CPO is above US$728/ton.[xiv] Today, CPO trades at US$697/ton in the domestic market, and with spiraling food inflation, demand for the commodity is falling. Releaf found that customers were unwilling to pay above US$674 per ton of CPO despite rising costs of production and food inflation nationwide. Consequently, the success of a BnS model is dependent on selling to an off-taker that pays a premium for the oil produced.

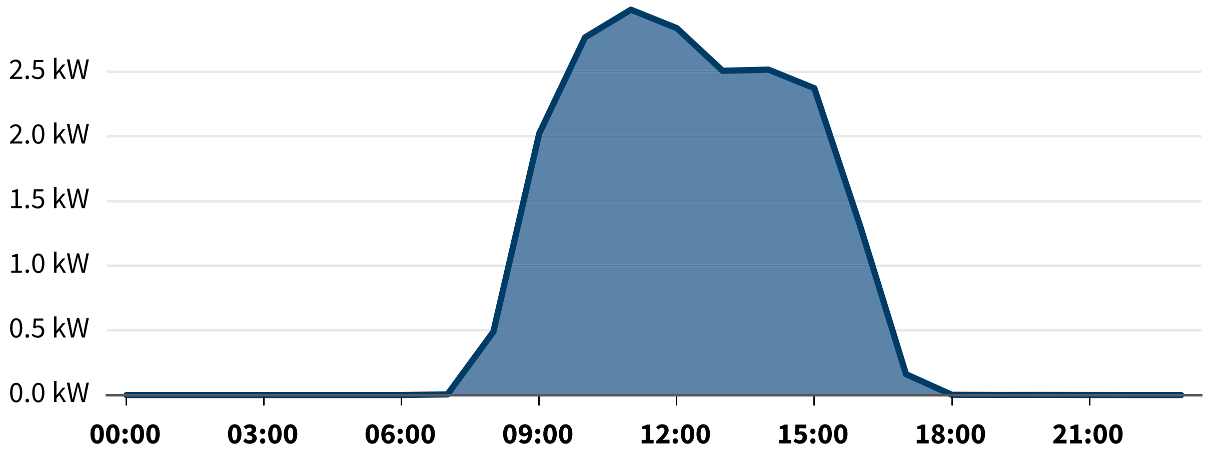
Electricity Use by the Oil Palm Mini-Factory

During peak season, the mini-factory contributed 20 kWh/day to the minigrid, equivalent to 75 times the daily consumption of a typical customer. The machines only ran during daytime hours when solar availability was high and residential demand was typically low (see Exhibit 19). Therefore, the facility utilized electricity that would otherwise have been curtailed. The mill added US$56 per month to the minigrid's revenues, about 20% of monthly electricity sales.

xiv For comparison, the price of fresh fruit bunches (FFB) is US$101/ton.

Exhibit 19

Average daily load from the oil palm mini-factory deployed by the accelerator



RMI Graphic. Source: EAP pilot data

Lessons Learned

The pilot project provided the following insights into critical enablers of sustainability and scale for rural oil palm processing facilities:

- **Adequate time and capital for customer adoption must be allocated before commercial operations begin because the process can be slow.** Although the facility was constructed and tested in April 2023, commercial operations started in September because of a lack of FFB and the community's reluctance to use the new facility. Additionally, other artisanal mills in the area expressed dissatisfaction with the project because it would affect demand for their services.

- **Equipment design should suit local crop species to ensure efficient operation and avoid breakdowns.** In the first three months of operation, the shaft in the nut-fiber separator fractured multiple times because it was designed to process *Tenera* species instead of the *Dura* species grown around Adebayo. Consequently, the processor incurred additional costs to redesign and install the component.

- **Building or providing local O&M capacity can minimize downtime and maintenance costs, which is critical to operational sustainability and profitability.** Several component failures (energy meters, electric motors, shafts) led to nonoperation for several days because replacement parts and technicians came from outside the community.

- **Business models based on offtake and trading are not viable unless the domestic demand for palm oil is sustained at higher prices, or CPO is exported at international trading prices.** Releaf planned to offtake CPO from the factory and retail in other domestic markets where the oil fetches higher prices (Kano, Lagos). However, when the commodity price increased beyond US$674/ton, demand attrition was high, making it difficult to realize the margins. In 2023, CPO traded internationally at US$838/ton. While local consumers are unwilling to pay this price, a processor that can export their CPO can realise a margin that would make an offtake-based model viable. [13]

Technician at the Adebayo mini-factory operates the nut-fiber separator. Photo credit: TNF Media

Scaling Plans

The pilot project's success has led team members to pursue opportunities to scale the business model. Releaf aims to close a Series A funding round in 2024 and replicate this business model in locations near its PKO production factory in Akwa Ibom state, where it has a strong network of suppliers that will ensure sufficient volumes reach the mill. There aren't any suitable minigrids currently, but Releaf is working with the Rural Electrification Agency to site future minigrids where they can be colocated with oil palm processing facilities.

Muhat Agro-Mech Ltd. has partnered with Afrimash, an online platform connecting farmers to agricultural inputs and equipment vendors. Developers with sites in Edo, Kogi, and Ondo states have expressed interest in supporting oil palm processors with modern equipment to encourage PUE. Muhat has visited some of their communities to assess the type and size of equipment needed for operations. Because these locations fall outside Releaf's catchment area, the potential partners are discussing who can be the aggregator/off-taker of CPO once produced.

3.5 CASE STUDY

Rice milling

In 2022, Mohammed Aliyu's diesel-powered rice mill cost more to run than he made selling the milled rice it produced, resulting in losses for his business. His experience was not unique. Smallholder farmers like Aliyu have seen diesel costs increase sixfold to US$1.01 per liter since the COVID-19 pandemic started in 2020. Additionally, because they rely on old, diesel-powered, single-stage mills that shatter up to 55% of grains that pass through them, smallholder farmers' poor-quality produce cannot compete with higher-priced imports that have flooded the market as rice has become a staple of the Nigerian diet.[14] Mohammed and his peers struggle as the Nigerian rice market booms. The Nigerian rice market is now worth US$4.7 billion each year and is projected to grow by 14% annually in the coming years.[15] Federal and state governments are keen to capture the value generated by rice cultivation, processing, and trade within their borders, but expensive processing has hindered smallholders from seeing the benefits.

There is a solution to Mohammed's plight: ditching his diesel-powered mill for an electric one. Electric rice mills are readily available on the market, can use cheaper energy, and limit breakage to 30% of grains. Yet, they are inaccessible to rural farmers for two main reasons: their steep up-front cost and a lack of electricity to power them. The proliferation of solar minigrids nationwide has brought 24/7 electricity to some rice communities, including Mohammed's town, Dancitagi. However, mill affordability remains a challenge. In 2022, the machine cost roughly NGN 430,000 (~US$1,000), almost 40% of Mohammed's annual income.[xv] As in many rural areas, credit availability and uptake in Dancitagi is low because of the population's lack of credit history, high lending rates, and cultural perceptions of debt.

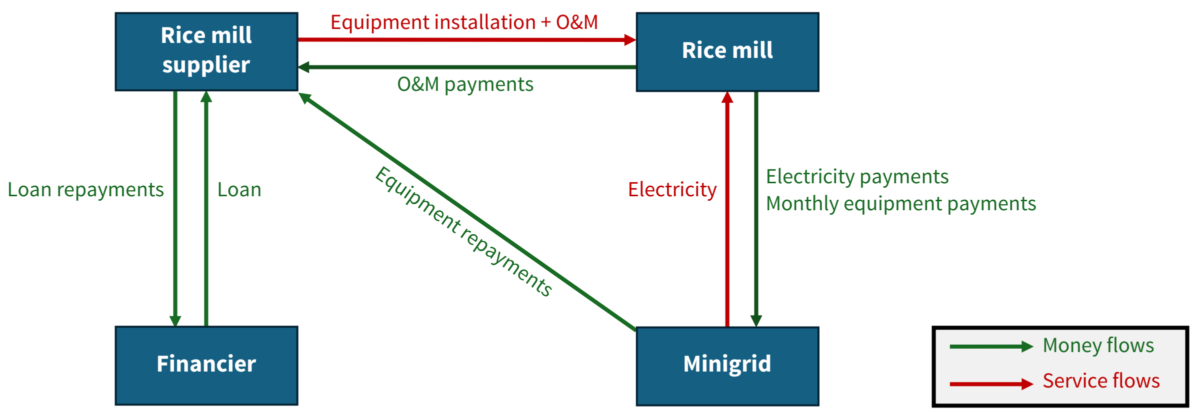
Business Model

The Rice Milling Accelerator team sought to address the challenges experienced by rural rice farmers by giving them access to electric rice mills at a low up-front cost. The accelerator brought together a rice mill supplier, Energy Excell, and a minigrid developer, PowerGen, to codesign a lease-to-own business model for rice milling. PowerGen, supported by the EAP grant, financed the purchase of five electric mills and

xv Price has been converted using the CBN exchange rate of NGN 417/US$ in August 2022.

deployed them to farmers in three of their minigrid communities in Niger state: Dancitagi, Ebangi, and Sa'achi Nku. Energy Excell, an importer and retailer of small agricultural machinery based in Abuja, provided all the equipment. The pilot project was set to operate for 12 months to test the performance and profitability of electric mills. In April 2023, the farmers paid PowerGen a 15% deposit (~US$40 at May 2024 exchange rate) to access the equipment. Since then, they have paid US$13 monthly. When the equipment cost is paid off after 18 months, the farmers will own the mills. The business model is illustrated in Exhibit 20.

Exhibit 20 Summary of the technical and economic performance of the rice mills deployed by the EAP accelerator



Pilot Description		Performance Summary	
Start date	April 12, 2023	**Up-front cost in 2022**	US$1,023
End date	December 31, 2023 (due to mill breakdowns)	**Sales modalities**	47% FFS 53% BnS
Location	Dancitagi, Niger state Ebangi, Niger state Sa'achi Nku, Niger state	**Gross revenues**	US$26,400 from rice sales US$450 from service fees
Minigrid developer	PowerGen	**Power consumption**	3,836 kWh
Equipment provider	Energy Excell	**Energy cost savings**	44%*
Beneficiaries	5 (3 male, 2 female)	**Direct jobs created**	7–9 (seasonality effect)
Equipment specifications	2.2 kW motor 200 kg/h throughput	**Payback period**	Not achieved
Processing fee	US$1.35 per 70 kg bag	**3-year IRR**	No positive cash flows
Milled rice sale price	US$89 per 70 kg bag	**3-year NPV**	−US$6,402

Note: *Small diesel mills consume an estimated 1.7 liters of diesel per ton of rice processed, while the Energy Excell mill consumed 25 kWh/ton.

RMI Graphic. Source: EAP pilot data

In December 2023, the pilot projects paused because all five rice mills had broken down beyond repair. The beneficiaries used untrained technicians to perform various repairs and retrofits to the mills, including electric motor replacements, fitting of larger feed hoppers, and sieve repairs. Before operations stalled, the five farmers had processed 1,402 bags of rice paddy (~98 tons) and contributed 3,840 kWh of additional electricity demand to the minigrids.

A cash flow model was used to assess the profitability of this business model without any grant funding and using typical Nigerian commercial financing terms. The terms are detailed in Exhibit 21. The cash flow analysis shows a positive business case for a mill run solely as an FFS business. The processor can repay their investment in about three months, delivering an IRR of 46% in three years. Afterward, their revenues outstrip the operational costs, including equipment repayments. However, BnS models fail to return a profit at today's paddy and milled rice prices. In July 2024, rice paddy retailed at US$37 per bag, while milled rice was sold in local markets at US$89 per bag. The rice mill yields 0.4 bags of milled rice for every bag of paddy processed.[xvi] At this yield, the price margin between paddy and milled rice is insufficient to get the BnS model to be profitable.

Exhibit 21 Commercial business model assumptions for lease-to-own rice milling

Assumptions		3-Year Indicators	Fee-for-Service	Buy-and-Sell
Down payment	15% of cost	**Payback period**	0.25 years	Not achieved
Financing terms	100% equity	**IRR**	46.1%	None
Minigrid tariff	US$0.19/kWh	**NPV**	US$718	−US$13,531
Length of lease	18 months	**Electricity sales**	US$1,734	US$1,734

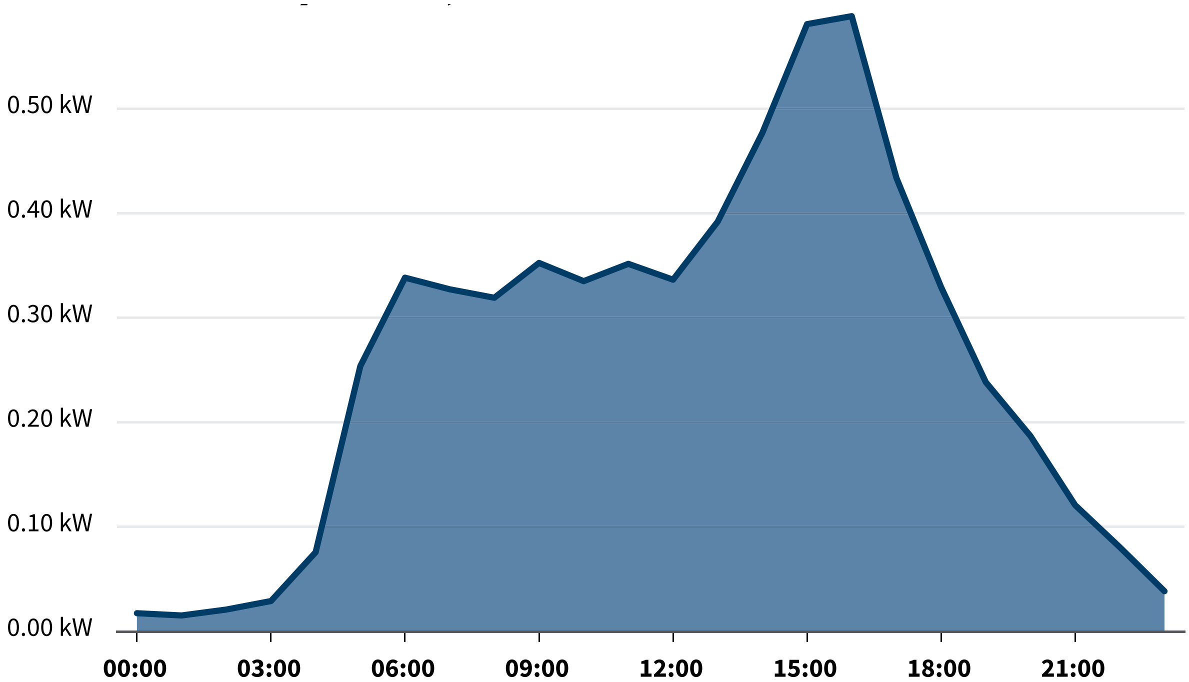
RMI Graphic. Source: EAP analysis

Electricity Use by Rice Mills

The rice mills deployed by the accelerator added an average of 6.2 kWh/day to the minigrid load. The machines were operated primarily during daytime hours, coinciding with low-cost solar availability (see Exhibit 22). Peak consumption occurred around 4 p.m., after which a steep decline occurred. Mill operation also complemented residential demand at the accelerator sites. During the day, residents typically worked on farms, so demand was low. Therefore, rice processors in the communities boosted the developer's previously low daytime sales.

xvi This is the yield of unbroken rice grains that can be sold in the market. Broken grains are kept for household consumption because they are used to make local dishes such as *masa* (rice cake) and *tuwon shinkafa* (rice swallow). The mill also produces rice husk and bran as waste products.

Exhibit 22 **Average daily load from the rice mill deployed by the accelerator**



RMI Graphic. Source: EAP pilot data

Lessons Learned

- **Inflation in operational costs outstripped food price increases, resulting in lower profitability of BnS sales.** The increase in the cost of rice paddy, minigrid electricity, and farm logistics has been greater than the increase in the price of milled rice. Between July and September 2023, rice paddy prices increased by ~50% to NGN 31,000 per bag, and the unit costs of labor, electricity, and netting replacement increased by 20%, 19%, and 11%, respectively. However, in the same period, the price of milled rice only increased by 8% to NGN 78,000 per 70 kg bag, leading to significant cuts in processor margins. Consequently, processors operating a typical BnS model have lower net profits than farmers who mill rice from their farms. Customers with integrated farming and milling operations are best positioned to yield the highest profit margins and be resilient to Nigeria's inflationary environment. Monthly surveys conducted by PowerGen showed that the size of net revenues directly correlated with the number of rice paddy bags processed from the millers' farms.

- **On-hand after-sales support within rural communities is essential for business model viability.** Processors needed to replace the screens in their mills within three months of operation. It took several weeks for Energy Excell to provide replacement parts. When millers had to wait for the spare part or a qualified person to install it, they tampered with machines to fix the problems. There have been several incidents of processors adapting the equipment, leading to breakdowns. In July 2023, two processors, Aliyu and Yahaya Mohammed Patigi, replaced the electric motors in their mills and experienced their lowest monthly profits. Furthermore, tampering resulted in equipment breakdown that halted operations for three months.

- **The intense customer engagement needed for payment collections and equipment maintenance discourages developers wanting to scale.** PowerGen reported increased utilization and sales on the minigrids since EAP equipment was deployed. However, it also emphasized the difficulty of manual payment collections and coordinating equipment repairs between processors and customers. It prefers to focus on providing quality electricity service in future projects and renege the responsibility for payment collections to another entity.

- **Designing equipment for customer needs is critical to the business model's success, and surveys are insufficient to determine those needs.** The accelerator surveyed 257 farmers across six minigrid communities to assess their equipment needs. Many overdeclared their crop production, resulting in oversized machines being purchased. Consequently, mill operations became unsustainable because farmers could not aggregate the rice volumes needed to deliver sufficient revenues.

- **A cluster approach is needed for an offtake-based business model.** This accelerator initially aimed to help farmers access higher-value markets. However, all rice aggregators engaged required volumes of about 30 tons monthly, well beyond the existing production capacity of many rural communities. A cluster approach would be needed to aggregate milled rice from multiple facilities and attract premium buyers.

Scaling Plans

Farmers at PowerGen sites have expressed strong interest in purchasing additional mills. Afrimash, an online marketplace for PUE equipment and an EAP partner, has established a warehouse and agent network across 12 of these communities in Niger state to sell more PUE equipment, including rice mills. It has also partnered with a fintech company, Owoafara, to pilot a credit scheme for 20 rice farms in Dukugi, Niger state, to receive loans for rice processing businesses under the model tested by the accelerator. At the 2023 Scaling Bootcamp, Energy Excell worked with several financiers and minigrid developers to determine a scaling pathway for the business model. The main barrier to scale remains consumer financing, which is needed to reduce the initial acquisition cost of the mills. Financiers, including impact investors (e.g., All On) and microlenders (e.g., Obtainly), expressed a desire to support scale if companies could aggregate their customers and conduct extensive due diligence on their repayment capacity. With a large enough list of vetted equipment buyers in hand, a loan facility for aggregated customers can be structured. Where equipment subsidies are available (e.g., via "results-based financing" facilities), financiers advised that these grants could serve as collateral for the loan facility.

EAP beneficiary operating rice mill in Ebangi, Niger state. Photo credit: TNF Media

4. Effect of PUE on Minigrid Economics

One Acre Fund agent, Kabiru, on an electric bike at Gwam, Niger state. Photo credit: TNF Media

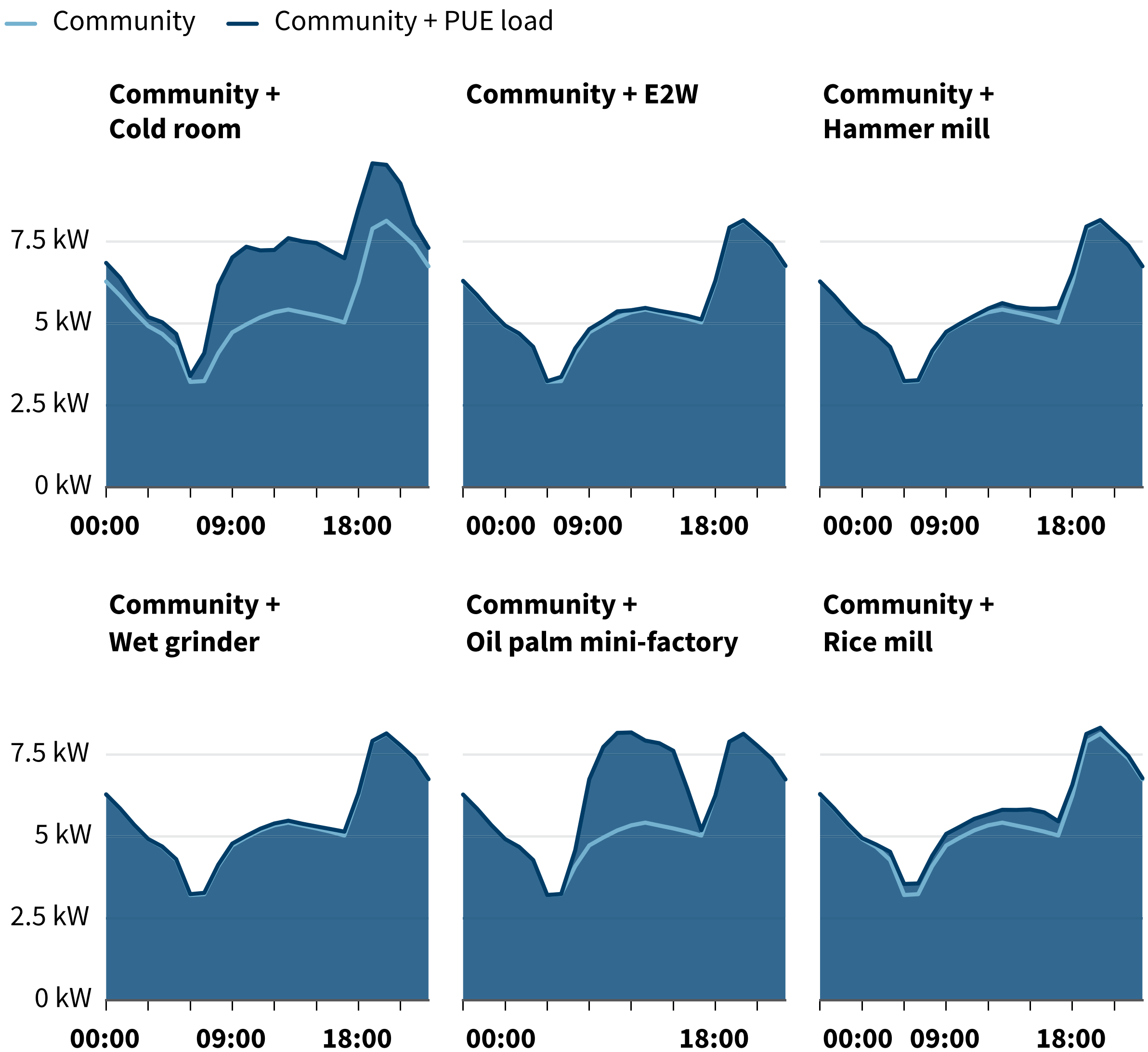
Section 3 discussed how six PUE equipment types deployed by the EAP accelerator (walk-in cold room, E2W, hammer mill, wet grinder, oil palm mini-factory, and rice mill) performed when deployed in minigrid communities. The machines varied greatly in their contributions to the demand for electricity in their host communities. The cold room consumed 34 kWh/day, the highest observed, while wet grinders added only 0.9 kWh/day on average. The disparity in loads means that the systems that can best meet these loads will differ. To understand how the additional demand impacted minigrid economics, we used HOMER to determine the least-cost system design to serve the baseline community load, with and without additional PUE loads (see Exhibit 23).

4.1 Effect of Adding Single PUE Loads on Minigrid System Design

The cold room and oil palm mini-factory have the largest impact on the minigrid load, though they alter the shape of the load curve differently. Electricity demand from the two types of PUE equipment requires a typical minigrid's solar capacity to increase by ~25%. However, battery storage capacity only increases slightly. Although the systems required to accommodate a cold room and oil palm mini-factory are similar, diesel use is 15% higher annually when a cold room is located in the community because it operates day and night. The oil palm facility adds only daytime load, causing demand on the minigrid to peak during peak sunlight hours.

Additional demand from the other four equipment types was small, and deploying just one of these units at a time had a negligible effect on the load curve and system design.

Exhibit 23 Least-cost system design for minigrids meeting baseline community and PUE loads



System design	No PUE	Cold room	E2W	Hammer mill	Wet grinder	Oil palm mini-factory	Rice mill
Photovoltaics (kW)	52.9	68.4	54.1	58.7	54.3	67.2	56.7
Diesel genset (kW)	16	20	16	17	16	22	17
Battery storage (kWh)	112	129	112	112	112	114	114
Inverter (kW)	12.7	15.3	12.6	12.4	12.3	13.8	12.7

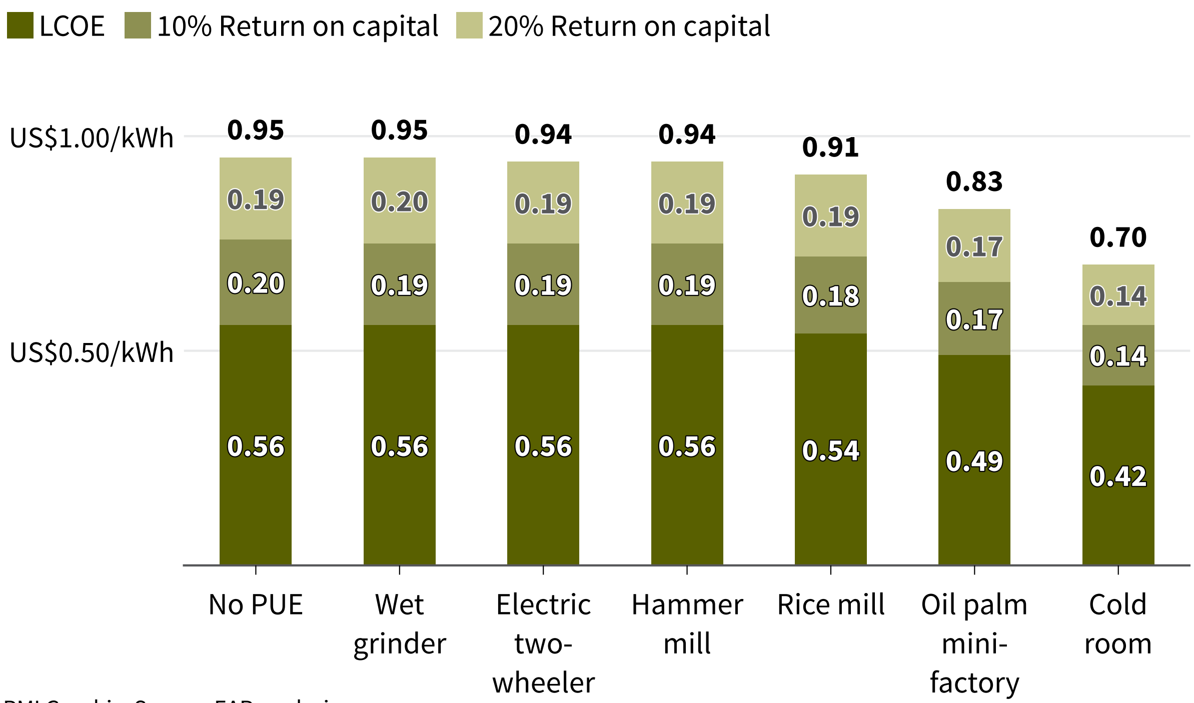
RMI Graphic. Source: EAP analysis

4.2 Effect of Adding Single PUE Loads to Minigrid Economics

We conducted cash flow analyses to see the extent to which **single** PUE loads can improve minigrid economics, particularly electricity affordability, in communities. The model calculated the minigrid's LCOE and tariffs needed to meet a target return on capital; the results are illustrated in Exhibit 24. We found that, while small loads have no observed impact, larger loads (e.g., cold rooms and oil palm processing facilities) can reduce the LCOE by up to 25%. Installing a cold room can reduce the tariff needed to deliver a 20% return on investment from US$0.95 to US$0.70/kWh. This would mean that a non-PUE customer who consumes 97 kWh annually can save US$24 on their energy spend. With rural household incomes averaging US$341 per year, this savings can free up 7% of earnings for other critical needs.[16,xvii]

Exhibit 24

Effect of PUE loads on minigrid economics



RMI Graphic. Source: EAP analysis

Although individual PUE interventions such as mills and electric motorcycles may have a limited impact on minigrid economics, they still have significant potential to transform energy access and affordability for rural communities when colocated and deployed at scale. Multiple pieces of PUE equipment can provide anchor loads for developers, bringing in consistent electricity sales and ensuring maximal system utilization.

This approach of scaling multiple PUE loads at minigrid sites is being trialed by developers looking to sustain the viability of their projects. One of those sites is the Chito community where a minigrid developer, Prado Power, has partnered with Farm Warehouse, a PUE company, to deploy agricultural equipment to its customers. We investigate Chito as a case study of how PUE deployment can transform minigrid economics and make energy cheaper for rural communities.

xvii Average rural household income is NGN 505,712/year, equivalent to US$341.

4.3 PUE at Scale: A Case Study of the Chito Community

Prado Power has built a 350 kWp minigrid at the Chito community in Ukum Local Government Area of Benue state, intending to serve up to 7,000 household, commercial, institutional, and PUE customers.[17] We built an **expected load curve** for the community to determine the grid's performance before and after equipment deployment using data collected from the EAP. Chito has 1,320 inhabitants, so we used the ACPU in Exhibit 4 to calculate their aggregate demand.[18] The expected community load profile is illustrated in Exhibit 25. We then evaluated the LCOE and tariffs for three scenarios:

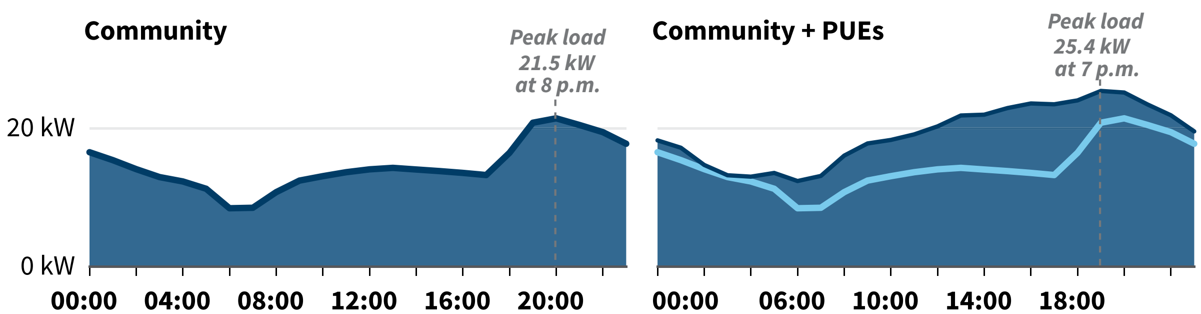
1. The **Baseline** scenario approximates the economics of the system like the one serving Chito today, but assuming no PUE deployment.

2. The **Baseline Optimized** scenario presents the economics of an optimized system (using HOMER) to meet **only the community load.**

3. The **Baseline + PUE Optimized** scenario presents the economics of an optimized system to meet the demand from the community load and PUE equipment sold to customers to date.

Exhibit 25

Effect of PUE on minigrid economics in Chito, Benue state



	Baseline	Baseline Optimized	Baseline + PUE Optimized
Non-PUE customers	1,320	1,320	1,320
PUE customers	0	0	29 (10 chest freezers, 10 hammer mills, 9 rice mills)
System design	**Photovoltaics:** 348.8 kWp **Battery:** 810 kWh **Genset:** 160 kVA	**Photovoltaics:** 173 kWp **Battery:** 297 kWh **Genset:** 51.3 kVA	**Photovoltaics:** 238 kWp **Battery:** 348 kWh **Genset:** 82.5 kVA
Minigrid capex	US$844,692	US$563,284	US$629,588
PUE capex	US$0	US$0	US$28,367
NPV of PUE electricity sales	US$0	US$0	US$118,363
LCOE	US$0.69/kWh	US$0.44/kWh	**US$0.35/kWh**
Tariff for 20% return	US$1.23/kWh	US$0.82/kWh	US$0.63/kWh

Note: kVA = kilovolt-ampere.

RMI Graphic. Source: EAP analysis

As sized today, the minigrid serving only its 1,320 residential customers would result in an LCOE of US$0.69/kWh. However, the system would be oversized. Rightsizing the minigrid for household demand would halve the photovoltaic (PV) capacity needed and reduce the LCOE by 36% to US$0.44/kWh. In Section 2, we showed that an average-sized minigrid has an LCOE of US$0.56/kWh. Thus, even with no PUE deployment, economies of scale can make energy access cheaper for rural populations.

The collaboration between Prado Power and Farm Warehouse has supported PUE adoption that reduces the minigrid's LCOE by almost half to US$0.35/kWh. We found that even a modest investment in PUE drastically decreases these energy costs further. A minigrid system that can serve both the household and PUE demand in Chito costs approximately US$630,000 to build and has an LCOE of US$0.35/kWh (see Exhibit 25). Adding PUE loads reduced LCOE by 49% relative to a no-PUE scenario. The 29 pieces of PUE equipment deployed currently cost an estimated US$28,000, or about 5% of the minigrid's capital expenditures. Yet, they contribute US$118,000 in electricity revenues over 20 years, five times the initial investment. Therefore, a small up-front investment in PUE in rural communities can be positively transformational for residents looking to access cheap energy and developers seeking higher utilization and revenues for their assets.

Our analysis shows that a 238 kWp minigrid can satisfy the community's electricity needs even after integrating the PUE equipment (see Exhibit 24). The existing minigrid (349 kWp) can easily accommodate these additional PUE loads. Farm Warehouse continues to retail appliances in Chito and other communities, aiming to deploy 500 units in the next 12 months. It also codeveloped a roadmap with Prado Power to achieve 3,000 PUE installations in the long term. Additional deployments at Chito will further improve the minigrid's commercial viability and reduce the cost of rural energy access.

The results in Section 4.3 suggest that Chito's minigrid is oversized for its current load, a common trend we have observed among existing minigrids in Nigeria today. The disparity in optimal and actual system designs exists for several reasons. HOMER optimizes minigrid designs for an exact load, which will likely evolve over time as demographics and energy consumption patterns change. Furthermore, HOMER's outputs are often at a granularity that developers cannot replicate because of standardized component sizes. More importantly, minigrid developers have multiple considerations when sizing their projects, including planning for future demand from additional customers, PUE integration or interconnection with the local grid. Finally, developers can oversize systems to ensure sufficient generation or storage capacity margins if components fail or solar resource availability isn't as predicted.

4.4 Designing Minigrids of the Future

Chito provides some insights on how the next cohort of minigrids should be designed to ensure their commercial viability and positive impact on livelihoods. Four factors have been critical to its success:

1. **Scale:** Chito is the largest isolated minigrid in the country and aims to serve 15 times the average number of connections observed at existing minigrids. The customer potential ensures that economies of scale, and thus more affordable energy, can be realized to an extent not seen in existing systems.

2. **System sizing:** The Chito minigrid, like others in the country, has spare capacity to accommodate additional demand from future residential and commercial customers. This has facilitated their partnership with Farm Warehouse because new PUE sales are easily integrated. Our results show that these PUEs are critical to making energy cheaper for rural customers. However, before PUEs are deployed, the developer requires a higher tariff to break even on their investment. Building

data-driven and modular systems would avoid higher prices for customers. A developer should size their system for existing demand but build the infrastructure modularly to allow for expansion. The developer and PUE company can then plan minigrid and PUE expansion in tandem, further driving energy costs down.

3. **Developer–PUE company partnership:** Prado Power and Farm Warehouse's partnership has allowed each company to focus on its core expertise in delivering scalable energy-agriculture solutions. Prado Power can concentrate on providing reliable electricity services, while Farm Warehouse assesses customer needs and facilitates the delivery of suitable appliances to residents. The EAP accelerator highlighted developers' hesitance to participate in consumer financing, payment collections, and other aspects of PUE sales. This partnership ensures that Prado Power avoids those challenges.

4. **Coordinated energy and PUE investment:** Prado Power received $1 million in funding from impact investors and donors to support the construction of Chito's minigrid.[19,xviii] Simultaneously, Farm Warehouse received support from CLASP's appliance financing facility, enabling it to supply cheaper PUE equipment. The colocation of philanthropic investment in Chito has allowed energy and agriculture solutions to be developed in tandem, which is mutually beneficial for their sustainability.

xviii Prado Power received US$1 million in financing from the Demand Aggregation for Renewable Technology (DART) program. DART is a global aggregated procurement program co-implemented by All On, Global Energy Alliance for People and Planet, and Odyssey Energy Solutions.

5. Recommendations

The EAP accelerator experience revealed the mutual benefits of PUE for minigrid developers and equipment suppliers. It also highlighted that PUE companies face several barriers to sustainable operations and scaling, which prevents them from realizing the opportunity in the energy sector in rural Nigeria, including the following:

1. **Inability to access financing.** PUE companies struggle to access corporate debt due to their lack of maturity and small-scale operations. Local financiers prefer established companies with a track record of consistent revenues and shun consumer financing because of the high cost of administering loans in rural areas. Consequently, PUE companies don't have the resources to reinvest in their businesses, and customers cannot access credit that will make equipment affordable.

2. **Inefficiencies in administering PAYGO for PUE in the field.** Few financiers cover rural areas, where most of the population is unbanked. Those present are reluctant to offer loans without unaffordable 4%–6% monthly interest rates. PUE companies can rarely fill this gap and offer equipment on credit because of the cost and operational complexity of handling payment collections in communities with which they have not built trust.

3. **Long lead times when equipment or parts need to be replaced or bought.** Due to limited working capital, PUE companies cannot maintain large inventories, and the slow speed of importing equipment into the country leads to supply chain constraints. Consequently, alternative vendors are sometimes required to meet customer needs when equipment breakdown or higher-than-expected demand occurs. Finding new suppliers requires additional time to conduct due diligence and complete procurement, during which entrepreneurs cannot run their agribusinesses. For example, a lack of spare parts led to a three-month pause in our rice milling pilot projects (see Section 3).

4. **Limited rural footprint and staffing lead to poor O&M service provision.** PUE companies struggle to provide timely O&M assistance because of limited staffing and the high cost of serving remote communities. When facing long lead times for equipment repair from the supplier, some customers attempt to fix equipment themselves or engage untrained technicians, risking total breakdown and reversion to diesel equipment.

5. **A mismatch between equipment specifications and customer needs.** Sometimes, the electric equipment on offer processes crops more slowly than incumbent diesel equipment. Suppliers face the challenge of offering a fast enough machine that is compatible with minigrid infrastructure and is affordable to the end-user. This is a prevalent challenge for more efficient electrical equipment, and it can lead farmers to overwork available equipment, resulting in frequent breakdowns and downtime, discouraging future customer adoption.[20]

6. **Volatile macroeconomic conditions lead to uncertainty in demand.** As described in Section 1.2, high inflation, multiple currency devaluations, and policy inconsistencies have prevented PUE companies from adequately planning their operations because of operational cost increases, supply chain disruptions, and customer demand attrition.

7. The multifaceted nature of these challenges means that scaling PUE interventions requires solutions from different energy and agriculture industry stakeholders, including PUE companies , rural utilities, government, investors, and the philanthropic community.

The government should use policy levers and financial resources to ease PUE companies' supply chain challenges and resource constraints.

To achieve this, the government should:

- Simplify import classifications and duties for equipment to speed up the process of importing equipment into the country.
- Exempt PUE equipment from value-added tax and customs duties to reduce the landed cost for customers.
- Channel state support to the PUE sector. State development banks (e.g., Bank of Agriculture and Bank of Industry) offer concessional loans and advisory support to farmers and businesses. The government can make PUE a priority industry and create or extend intervention programs to PUE companies.
- Develop rural electrification policies emphasizing PUE and codesign state-led energy and agriculture interventions to facilitate coordination between ministries and cross-sectoral collaboration between private actors.
- Use the Rural Electrification Agency to support PUE companies in identifying expansion opportunities by publicizing the coordinates of each permitted minigrid in the country.
- Design and implement quality standards for PUE appliances to ensure their efficiency, longevity, and safety for customers.

The PUE ecosystem must determine how to guarantee equipment reliability through prompt O&M service delivery in rural communities and efficiently implement PAYGO models that increase the affordability of PUE equipment.

That includes:

- Investing in data collection to understand which type and scale of equipment is most suitable for customers in different agricultural value chains. Standardized equipment may require modifications to process local species efficiently, so PUE companies must work with manufacturers to design the right product for their customers.
- Building local O&M capacity near customer locations to reduce maintenance turnaround times by ensuring a sufficient inventory of spare parts, training local technicians to carry out basic maintenance, and investing in logistics infrastructure that allows staff to troubleshoot remotely.
- Exploring partnerships to share infrastructure and business functions (e.g., warehouses, last-mile delivery network, customer service, and payment collections) with other rural service providers to reduce operational costs and challenges.

The minigrid ecosystem must support PUE and energy supply in tandem. Support for energy-only solutions leads to underutilized and unsustainable generation assets.

This support will require:

- Surveying the PUE opportunities at potential locations before designing and constructing the minigrids and developing a plan to realize the PUE potential at sites, including the necessary partnerships to deliver win-win business models.

- Ensuring that expertise in building and scaling PUE interventions (partnership building, equipment appraisal, site selection, integration) is preserved within the company by improving staff retention rates or standardizing training for new staff that are responsible for PUE.

Investors must support nascent companies to realize the US$120 billion PUE market opportunity in sub-Saharan Africa.[21]

The EAP has shown that significant value can be created across several agricultural value chains with limited investment. It has also identified the type of investment support PUE companies need to scale further such as:

- Working capital loans and inventory finance to ensure PUE companies have sufficient liquidity to maintain their supply chains and last-mile delivery.

- Guarantees or credit lines to local financiers to incentivize them to implement consumer financing schemes targeting rural areas.

- Equity investment that can support equipment design and manufacturing, business setup, and expansion without burdening companies with interest payments. Equity investors also bring expertise and make it easier to raise debt financing later.

Donors should focus grant support on non-revenue-generating activities critical to the PUE industry's success.

Minigrid and PUE companies lack the resources to identify the best locations for energy-agriculture solutions and how those solutions should be designed. Philanthropic funding can fill this gap through several initiatives such as:

- Providing funding to companies for needs assessments and customer engagement activities to determine the PUE potential at prospective sites.

- Creating a coordination platform for different funders to understand PUE potential in their sector of interest (health, agriculture, etc.) and invest.

- Supporting establishment of an industry association for PUE companies to facilitate knowledge sharing, partnership building, and coordinated advocacy efforts.

- Continuing to support early-stage projects that are yet to reach commercial viability.

Appendix A: Minigrid Modeling Assumptions

HOMER software requires several inputs to determine the least-cost minigrid system design that meets a specified load. The inputs for the analysis presented in this report are detailed below.

HOMER Assumption	Definition	Assumption
Daily load profile	Expected hourly load on minigrid	See Section 2
Location	GPS coordinates of the minigrid site	Abuja, Nigeria[xix]
Capacity shortage	Shortfall allowed between the required load and the load the system is providing	0%
Solar resource data	Source of solar radiation data	National Renewable Energy Laboratory data[xx]
Day-to-day variability	Random variability factor for day-to-day loads	10%
Time step variability	Random variability factor for hour-to-hour loads	20%
Component costs	Capital and O&M costs for each system component	See below
Discount rate	Rate of return used to discount future cash flows back to their present value	20%
Inflation rate	Rate at which costs increase over time	2%

Next page: Cost assumptions in the minigrid cash flow model

xix Unless location otherwise specified.

xx National Renewable Energy Laboratory's National Solar Radiation Database.

The table below details the cost assumptions in the minigrid cash flow model.

Economic Assumptions	Value	Source
Initial NGN/US$ exchange rate	1,483	Central Bank of Nigeria rate on May 31, 2024
NGN/US$ annual depreciation rate	2%	—
Initial diesel price	US$1.01/liter	EAP accelerator projects
Initial minigrid tariff	US$0.19/kWh	EAP accelerator projects
Financing Assumptions		
Debt-equity split	30%–70%	RMI cost database[xxi]
Cost of debt	10%	RMI cost database
Cost of equity	25%	RMI cost database
Grant per connection	US$600	World Bank Nigeria Electrification Project
Target project US$ IRR	20%	RMI cost database
Technology Cost Assumptions		
Solar PV panel	US$200/kWp	Rural Electrification Agency and RMI cost databases
PV cost reduction	4% year-over-year	RMI cost database
Deep cycle battery bank with racking system[xxii]	US$327/kWh	Rural Electrification Agency and RMI cost databases
Battery storage cost reduction	4% year-over-year	RMI cost database
Inverter	US$53/kWp	Rural Electrification Agency and RMI cost databases
Diesel genset	US$181/kW	Rural Electrification Agency and RMI cost databases
Low-voltage distribution network	US$11/m	RMI cost database
O&M cost increase rate	5% year-over-year	RMI cost database
Other Assumptions		
Non-PUE load growth	2% year-over-year	Minigrid developers
Revenue collection efficiency	90%	Minigrid developers

xxi The RMI cost database includes data provided by minigrid developers, investors, and other industry stakeholders during the implementation of various off-grid and grid-connected distributed energy resource projects.

xxii Battery specifications: Lithium-ion phosphate battery, 4.4–5.37 kWh usable, 7,000 cycles to 90% depth of discharge.

Appendix B: Effect of Macroeconomic Indicators on Minigrid Economics

The following tables detail how different macroeconomic assumptions impact the LCOE from a minigrid serving 500 connections.

Diesel price (US$/liter)	0.50	0.75	1.00	1.25	1.50
Diesel price (NGN/liter)	742	1,112	1,483	1,854	2,225
LCOE (US$/kWh)	0.54	0.55	0.56	0.57	0.58
Tariff for 10% return on capital (US$/kWh)	0.73	0.75	0.76	0.77	0.78
Tariff for 20% return on capital (US$/kWh)	0.93	0.94	0.95	0.96	0.97

Annual O&M cost increase	0%	5%	10%	15%	20%
LCOE ($/kWh)	0.42	0.56	0.83	1.34	2.34
Tariff for 10% return on capital (US$/kWh)	0.63	0.76	1.00	1.47	2.54
Tariff for 20% return on capital (US$/kWh)	0.82	0.95	1.20	1.66	2.74

NGN/US$ exchange rate	500	1,000	1,500	2,000	2,500
LCOE (US$/kWh)	0.65	0.58	0.56	0.55	0.54
LCOE (NGN/kWh)	325	580	840	1,100	1,350
Tariff for 10% return on capital (US$/kWh)	0.84	0.78	0.76	0.75	0.74
Tariff for 20% return on capital (US$/kWh)	1.04	0.97	0.95	0.94	0.93

Appendix C: Sensitivity Analysis for Cold Storage Business Model

The following tables detail the impact of business model assumptions on the profitability of a minigrid-powered walk-in cold room.

Minigrid tariff (US$/kWh)	Baseline	0.1	0.2	0.3	0.4	0.5
Payback period (years)	4.50	4.50	5.08	6.00	7.17	9.25
10-year IRR	16.3%	16.6%	13.4%	10.2%	7.0%	3.7%
10-year NPV (US$)	19,433	19,800	15,151	10,488	5,810	1,132
10-year electricity payments (US$)	32,254	29,905	59,682	89,460	119,237	149,014

PUE tariff discount (%)	Baseline	0%	10%	20%	30%	40%
Payback period (years)	4.50	4.50	4.50	4.42	4.33	4.33
10-year IRR	16.3%	16.3%	16.7%	17.0%	17.4%	17.7%
10-year NPV (US$)	19,433	19,433	19,935	20,434	20,932	21,431
10-year electricity payments (US$)	32,254	32,254	29,042	25,829	22,616	19,404

Volumes stored (kg/month)	Baseline	3,000	4,500	6,000	7,500	9,000
Payback period (years)	4.50	None	6.50	4.50	3.67	3.17
10-year IRR	16.3%	−1.2%	8.4%	16.3%	23.3%	29.4%
10-year NPV (US$)	19,433	−4,980	7,438	19,433	31,174	42,701
10-year electricity payments (US$)	32,254	32,254	32,254	32,254	32,254	32,254

Gross margin on fish (NGN/kg)	Baseline	200	300	400	500	600
Gross margin on fish (US$/kg)	0.27	0.13	0.20	0.27	0.34	0.40
Payback period (years)	4.50	None	6.83	4.50	3.50	2.92
10-year IRR	16.3%	−1.9%	7.7%	16.3%	24.5%	32.2%
10-year NPV (US$)	19,433	−6,141	6,667	19,433	32,147	44,825
10-year electricity payments (US$)	32,254	32,254	32,254	32,254	32,254	32,254

Grant received (% of capex)	Baseline	0%	10%	20%	30%	40%
Payback period (years)	4.50	4.50	4.33	4.08	3.92	3.75
10-year IRR	16.3%	16.3%	18.7%	21.1%	23.6%	26.1%
10-year NPV (US$)	19,433	19,433	23,769	28,681	34,264	40,623
10-year electricity payments (US$)	32,254	32,254	32,254	32,254	32,254	32,254

Appendix D: Sensitivity Analysis for Electric Mobility Business Model

The following tables detail the effect of energy and vehicle costs on the TCO of petrol and E2Ws being used for farm logistics.

Minigrid tariff (US$/kWh)	Baseline	0.1	0.2	0.3	0.4	0.5
TCO for ICE (US$/km)	26.80	26.80	26.80	26.80	26.80	26.80
TCO for E2W (US$/km)	21.50	20.05	22.68	25.32	27.96	30.60

Petrol price (US$/liter)	Baseline	0.6	0.7	0.8	0.9	1
TCO for ICE (US$/km)	26.80	24.62	27.55	30.48	33.41	36.35
TCO for E2W (US$/km)	21.50	21.50	21.50	21.50	21.50	21.50

E2W capex (US$)	Baseline	1,000	1,500	2,000	2,500	3,000
TCO for ICE (US$/km)	26.80	26.80	26.80	26.80	26.80	26.80
TCO for E2W (US$/km)	21.50	13.89	19.18	24.46	29.75	35.03

ICE capex (US$)	Baseline	500	750	1,000	1,250	1,500
TCO for ICE (US$/km)	26.80	26.60	29.24	31.88	34.52	37.17
TCO for E2W (US$/km)	21.50	21.50	21.50	21.50	21.50	21.50

Appendix E: Sensitivity Analysis for Oil Palm Processing Business Model

The tables below detail the impact of key variables on the profitability of a small-scale oil palm processing facility.

Change in capex	Baseline	−50%	−25%	0%	50%	100%
Payback period (years)	1.33	0.25	0.42	1.33	3.17	4.50
3-year IRR	8.1%	30.7%	15.2%	8.1%	1.3%	−2.2%
3-year NPV (US$)	3,770	7,517	5,647	3,770	−304	−4,445

Minigrid tariff (US$/kWh)	Baseline	0.1	0.2	0.3	0.4	0.5
Payback period (years)	1.33	1.25	1.42	2.17	2.33	2.42
3-year IRR	8.1%	8.3%	7.0%	5.7%	4.3%	3.0%
3-year NPV (US$)	3,770	3,888	3,138	2,368	1,575	781

Share of BnS sales	Baseline	0%	25%	50%	75%	100%
Payback period (years)	1.33	1.33	2.17	2.50	3.50	5.42
3-year IRR	8.1%	8.1%	5.3%	2.5%	-0.3%	-3.5%
3-year NPV (US$)	3,770	3,770	2,180	530	−1,119	−2,796

Service fee (US$/drum)	Baseline	1	1.5	2	2.5	3
Payback period (years)	1.33	11.92	3.17	1.33	0.42	0.33
3-year IRR	8.1%	−6.9%	1.1%	7.8%	14.4%	21.4%
3-year NPV (US$)	3,770	−4,340	−297	3,598	7,286	10,936

Grant investment (%)	Baseline	0%	25%	50%	75%	100%
Payback period (years)	1.33	1.33	1.08	0.42	0.42	0.42
3-year IRR	8.1%	8.1%	11.6%	15.2%	18.7%	18.7%
3-year NPV (US$)	3,770	3,770	5,484	7,191	8,882	8,882

Lease period (months)	Baseline	6	12	18	24	30
Payback period (years)	0.58	1.25	1.17	0.58	0.58	0.58
3-year IRR	20.6%	9.6%	14.6%	20.6%	25.7%	29.0%
3-year NPV (US$)	316	291	313	316	325	328

CPO sale price (US$/drum)	Baseline	15	16	17	18	19
Payback period (years)	5.42	None	2.25	0.33	0.25	0.25
3-year IRR	−3.5%	None	4.8%	21.0%	37.5%	52.6%
3-year NPV (US$)	−2,796	−8,371	1,880	10,760	19,499	28,237

Appendix F: Sensitivity Analysis for Rice Milling Business Model

The tables below detail the impact of key variables on the profitability of a small-scale rice milling business.

Minigrid tariff (US$/kWh)	Baseline	0.1	0.2	0.3	0.4	0.5
Payback period (years)	0.25	0.17	0.25	1.67	None	None
3-year IRR	46.1%	75.0%	43.4%	9.0%	None	None
3-year NPV (US$)	718	1,203	677	151	−433	−1,149

BnS sales (%)	Baseline	0%	25%	50%	75%	100%
Payback period (years)	0.25	0.25	None	None	None	None
3-year IRR	46.1%	46.1%	None	None	None	None
3-year NPV (US$)	718	718	−2,571	−6,224	−9,878	−13,531

Service charge (US$/bag)	Baseline	1	1.5	2	2.5	3
Payback period (years)	0.25	2.58	0.17	0.17	0.17	0.17
3-year IRR	46.1%	3.4%	63.8%	115.2%	160.1%	198.2%
3-year NPV (US$)	718	43	1,009	1,970	2,918	3,849

Lease duration (months)	Baseline	6	12	18	24	30
Payback period (years)	0.25	0.67	0.25	0.25	0.17	0.17
3-year IRR	46.1%	21.6%	36.3%	46.1%	51.3%	54.4%
3-year NPV (US$)	718	697	715	718	728	732

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