

POWERING MINI-GRIDS WITH EFFICIENT MILLING

THE ROLE OF
ENERGY-EFFICIENT
MILLING OPERATIONS
IN STRENGTHENING
OFF-GRID SYSTEM
SUSTAINABILITY IN
NORTHERN UGANDA

SEPTEMBER 02, 2026

Efficiency for Access Coalition

Poorly Maintained Milling Machine with Motor
and Switchgear.

Source: Energy Efficiency Association of Uganda.



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ABBREVIATIONS

CES	Customized Energy Solutions
EACREEE	East African Center of Excellence for Renewable Energy and Efficiency
EEAU	Energy Efficiency Association of Uganda
ENMS	Energy Management System
HP	Horsepower
IRR	Internal Rate of Return
KG	Kilogram
kVA	Kilo Volt Ampere
kVAH	Kilovolt-ampere-hour
kVAR	Kilovolt-ampere reactive
kW	Kilo Watt
kWH	Kilowatt-hour
M	Miller
MW	Mega Watt
MWH	Megawatt-hour
NOA	NEoT Off-grid Africa
NPV	Net Present Value
PUE	Power Usage Effectiveness
SUP	Supplier
TC	Trading Centre

UGX	Uganda Shillings
VFDs	Variable Frequency Drives

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EXECUTIVE SUMMARY

This study assesses the electricity consumption patterns, technical performance, and socio-economic implications of solar mini-grids supporting grain milling in Lamwo District, Northern Uganda. The assessment combined metered energy measurements from three grain-milling customers across the Ogili and Muddu Central mini-grid sites, measurements at the Apyetta mini-grid, and key informant interviews with nine stakeholders. The findings show that grain milling is an important productive-use anchor load, and that milling equipment performance directly affects electricity costs, mini-grid reliability, equipment life, and the broader economic benefits of rural electrification. Awareness is a key intervention to transform the sustainability and reliability of mini-grids and downstream services, as is the case with milling.

KEY FINDINGS

Figure 1: The unintended consequences of energy-inefficient milling on mini-grids in Lamwo District
(Source: Author's elaboration)

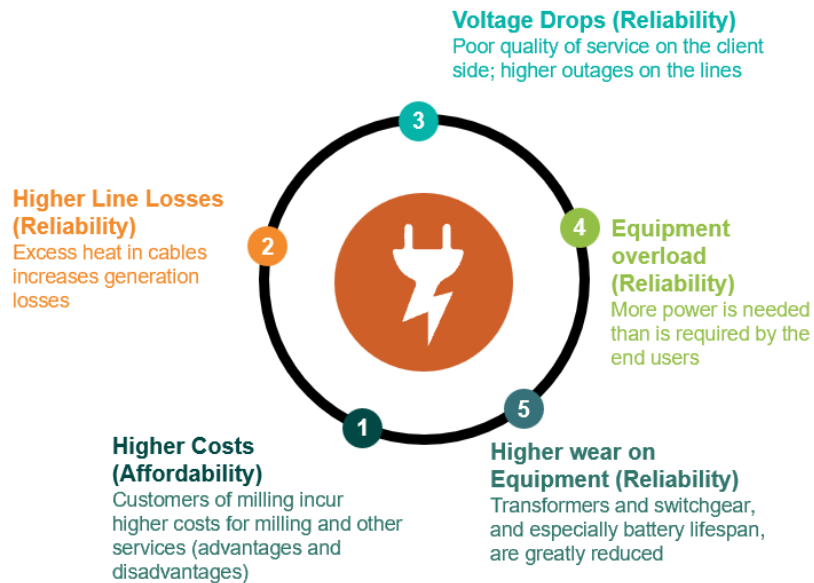


Figure 1 above shows the unintended consequences of inefficient milling on the Mini-grid and further illustrates the impact on sustainability. Specifically, the three assessed milling machines consume an average of 251.8 kWh, 178.26 kWh, and 240.31 kWh per month, respectively. These figures indicate that milling is a productive-use material load, but operating practices, equipment efficiency, and available mini-grid capacity influence its contribution to overall system utilization.

The reliability indicators further highlight the operational challenge. Ogili recorded a SAIFI of 9 and a SAIDI of 35 hours, while Apyetta recorded a SAIFI of 47 and a SAIDI of 217 hours; comparable reliability data were not available for Muddu Central. The assessment indicates that a substantial share of the interruptions is attributable to energy-limited operation and system capacity constraints. Improving end-use efficiency can therefore reduce unnecessary demand for generation, inverter, and battery assets and help improve

the reliability, sustainability, and effective utilization of the mini-grids.

Power-quality measurements also identified inefficient electrical operation of the milling loads. The three milling customers recorded low power factors of 0.55 at Muddu Central for customer #1, 0.45 at Ogili TC for customer #2, and 0.78 at Ogili for customer #3. All three sites also recorded high reactive power, with Muddu Central (customer #1) accounting for 33.14 kVAR, 33.14 kVAR for Ogili TC (customer #2), and 20.29 kVAR for Ogili (customer #3). Reactive-power demand increases current loading and can contribute to voltage fluctuations, higher operating costs, and accelerated motor wear. The study also found that none of the mill

operators maintained formal production records or structured maintenance schedules. Dust accumulation, inconsistent lubrication, and corrective rather than preventive maintenance practices further undermine motor performance and equipment life.

The motors assessed were predominantly IE2 high-efficiency motors, with one IE3 premium-efficiency motor. The assessment found that technical solutions alone will not deliver their full value unless customers and mini-grid personnel have the **awareness and skills required to operate and maintain equipment efficiently**. The socio-economic benefits of improving milling efficiency extend beyond the mill itself, including improved productivity and revenue, reduced downtime, household welfare and food security, employment, market development, and greater participation of women and youth in electricity-enabled economic activities.

The evidence therefore points to a phased approach in which awareness, capacity

building, record keeping, and energy management are established as the foundation for technical upgrades. Priority interventions include implementing an energy management system, improving operational and production records, power-factor correction, replacing soft starters with variable-frequency drives where appropriate, and progressively replacing IE2 motors with IE3 or even IE4 motors. The study also recommends that NOA review the capacity of the Ogili and Apyetta systems, particularly battery capacity, and replace them with lithium batteries to address reliability constraints. The business case for the identified technical measures is favorable, with the report estimating short payback periods for power-factor correction and VFDs

recommend targeted interventions that improve stakeholders' awareness and capacity for energy conservation and the implementation of energy-efficiency measures, especially initiatives and practices that enhance mill efficiency. This has a high likelihood of acceptance, as the team will disseminate findings to the NOA management and technical teams. As NOA confirms, this is the most important first step with ripple positive effects at the milling sites.

RECOMMENDATIONS

The following recommendations are arranged from low to high cost to enable Mini-grid developers and mill operators to implement them immediately and realize socio-economic value.

Low Cost:

Mini-Grid Recommendations

- **Awareness and capacity building:** The level of awareness and capacity building on energy efficiency in mini-grid sites and productive use enterprises is still low. We

Milling Site Recommendations

- **Record keeping:** The grain millers that were visited were not keeping track of energy and production records. We recommend that the millers employ competent staff who can maintain proper records. Record keeping helps companies understand their performance

daily, enabling them to improve energy efficiency by implementing initiatives with clear before-and-after evidence. The NOA management team indicates that this is the next top-priority recommendation for adoption, as it will improve the mini-grids' generation operations.

Mini-Grid Recommendations

- **Implementation of the energy management system:** An energy management system (EnMS) is a framework for energy consumers, including industrial, commercial, and public sector organizations, to manage their energy use following Energy Management Systems (EnMS) such as ISO 50001. It helps companies identify opportunities to adopt and improve energy-saving measures through energy conservation and the deployment of efficient technologies, including those that do not necessarily require high capital investment, using a sustainable, Plan-Do-Check-Act-consistent framework. This involves developing and implementing an energy policy, setting achievable energy-use targets, designing action plans to meet them, and measuring progress. We recommend that mini-grid sites NOA integrate an EnMS into their new site design, milling operations deployments, and ongoing maintenance initiatives. This will enhance Mini-grid sustainability in the long run and the socio-economic benefits of milling operations in the region.

High Cost

Milling Site Recommendations

- **Power factor correction:** We recommend that capacitor banks be installed in all grain mills in Lamwo District, Northern Uganda. The expected savings from installing capacitor banks are 10-15%. This will also enhance site reliability by reducing unnecessary high current draw from motors relative to the actual power needed, increasing motor lifespan, and providing economic benefits to mill operators and NOA. Power Factor correction must also be incorporated in the planning for future sites with guidance from NOA's (Mini-Grid Site) Business Development team. Specifically for large customers, there is an opportunity to install KVAR meters to track power factor and use the data to penalize those that fall below the recommended level (below 0.8).

The estimate is 800,000 Ugandan shillings. Annual energy savings of 7,2444.6 kWh and 7,766,254 Ugandan shillings. Simple Payback Period of 0.1 years. Net present value (NPV) of 52,094,904 Ugandan shillings and Internal Rate of Return (IRR) >90%. The project is technically feasible and financially viable.

- **Installation of Variable Frequency Drives (VFDs):** We recommend that the soft starters in the grain mills be replaced with VFDs, which will also enhance motor lifespans and increase site reliability. The expected energy savings from installing VFDs range from 20% to 50%. VFDs must also be incorporated in the planning for future sites with guidance from NOA's

(Mini-Grid Site) Business Development and management teams.

The estimated investment cost for a 220V, 15 HP (11 kW), vector-controlled, variable-frequency drive inverter motor CNC is 1,640,000 Ugandan Shillings. Annual energy savings are 3,113.3 kWh and 3,337,404 Ugandan shillings. The simple payback period is 0.49 years. The net present value (NPV) is 21,090,606 Ugandan shillings, and the internal rate of Return (IRR) is 205%. This makes the project technically feasible and financially viable.

- **Replacement of induction motors with more energy-efficient ones:** We recommend that the IE2 induction motors be replaced with IE3 motors or even IE4 motors to increase energy efficiency, lower energy costs, and enhance the reliability of the sites. The estimated investment cost for a 15kW IE3 induction motor is 1,850,000 Uganda Shillings. Annual energy savings are 986 kWh and 1,056,992 Uganda Shillings. The simple payback period is 2.9 years. Net present value (NPV) of 5,349,084 Uganda Shillings and Internal Rate of Return (IRR) of 57.4%. This recommendation is technically feasible and financially viable. The use of energy-efficient motors must also be incorporated into the planning for

future sites, with guidance from NOA's (Mini-Grid Site) Business Development.

Milling Site Recommendations

- **Review of System Capacity to Enhance Reliability:** We recommend that the NOA Business Development team and Management review the capacity of the Apyetta Mini-Grid site and Ogili Mini-Grid site to ensure that the battery capacity, especially, is enhanced to cater for the high reliability issues experienced on these sites. The cost and business case for these recommendations will need to be considered on a case-by-case basis; however, the benefits in terms of enhanced reliability are worthwhile. In addition, we recommend replacing all lead-acid batteries at these sites with lithium-ion batteries to enhance reliability.

Affordability Recommendations

On-bill Mechanisms: We recommend that the NOA Business Development team develop an on-bill mechanism to offset the cost of investing in efficient technologies, such as VFDs, capacity banks, and IE3 & IE4 super-efficient and premium-efficient motors, for milling customers, with cost recovery spread over an agreed period on the customer's energy bill.

CONCLUSION

NOA Uganda's mini-grids are not being undermined by a shortage of generation capacity or connections, but by the absence of routine, low-cost energy-management behavior at the point of consumption. Power factors as low as 0.45, motors run persistently below 25% of rated load,

and outage logs of up to 18 hours at a single site all trace back to the same root cause: milling customers, and the mini-grid operator supporting them, have never been equipped with the awareness and basic skills to use electricity efficiently. None of the technical fixes identified power factor correction, right-sized or variable-speed motors, premium-efficiency replacements can be adopted by a customer who does not yet know they have a problem, what it is costing them, or that a solution exists.

This is precisely why awareness is the activity that merits grant financing now, ahead of and as a precondition for any equipment or financing intervention:

- **It closes a genuine knowledge gap, not a technology gap.** Pilot customers were found repairing or replacing burnt-out motors without ever learning that dust build-up, missed lubrication, and poor load aggregation were the cause of a knowledge gap that costs nothing to close but was never addressed.
- **It is the lowest-cost, highest-leverage entry point.** The cost-benefit analysis shows some of the strongest returns available anywhere in the mini-grid value chain (power factor correction alone pays back in roughly a month, with an IRR over 90%). Still, that return is inaccessible until customers and NOA staff know it exists and how to act on it. Awareness is the low-cost unlock for a high-return opportunity.
- **It is a one-time investment with a multiplying, pipeline-wide return.** With 93 new mini-grid sites in NOA's pipeline, every efficiency habit and monitoring practice instilled now becomes standard operating procedure at scale, rather than a costly retrofit later. Funding awareness today is materially cheaper than correcting embedded inefficiency across dozens of future sites.
- **Demand for efficiency already exists and is currently going unmet.** The pilot already shows stimulated interest among consumers eager to invest once they understand the benefit, confirming that awareness activity converts directly into demand, and that the constraint today is information, not appetite.

We therefore recommend that the funder prioritize financing for awareness and capacity building. These activities are most directly responsible for converting NOA's existing mini-grid and PUE investments into sustainable, efficiently used assets, protecting the funder's and NOA's prior investment in electrification, improving mini-grid revenue and reliability, and building the customer-level foundation that later financing and equipment-upgrade support will depend on. Awareness is not a preliminary step to the real intervention on the evidence gathered; it is the intervention with the most immediate, lowest-risk, and widest-reaching impact available to fund. Table 1 below presents an estimate of the cost of implementing this intervention across 20 pre-qualified sites.

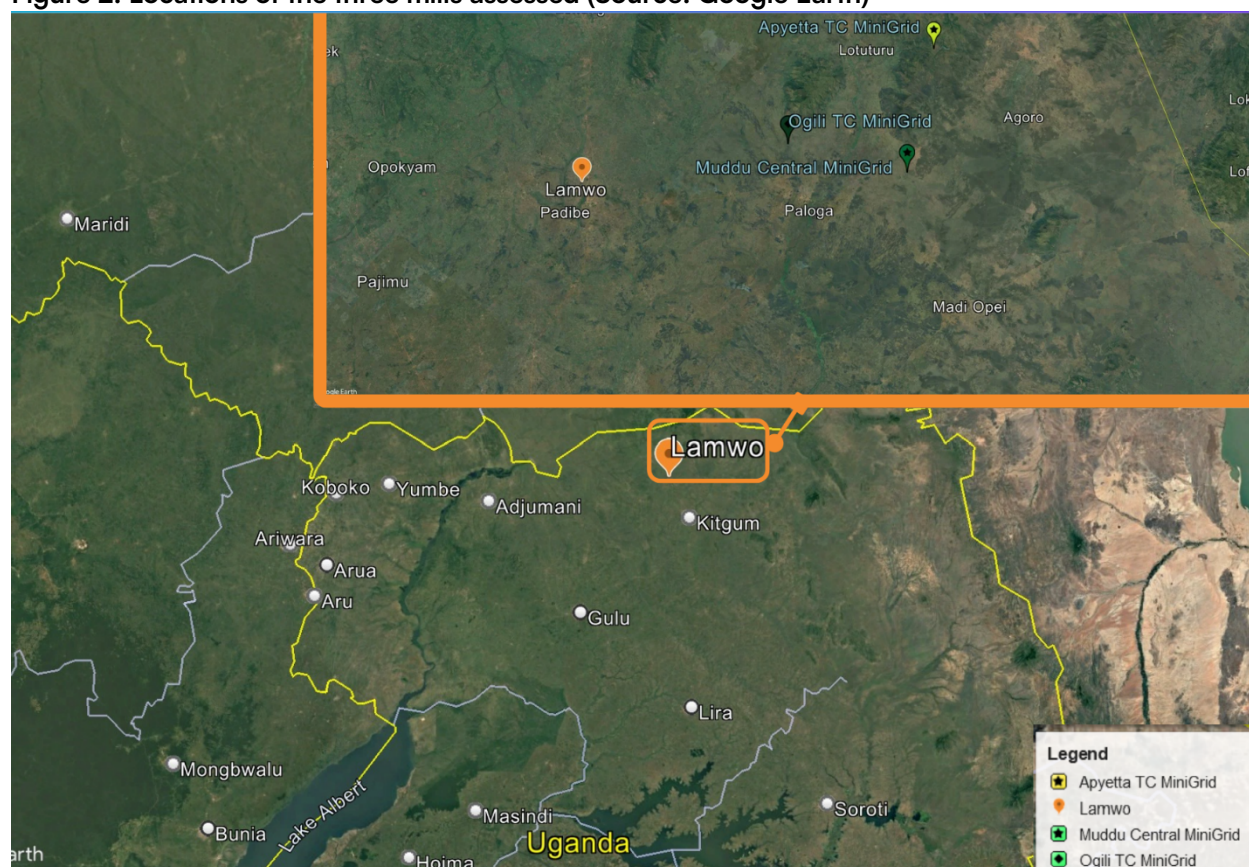
Table 1: Summary of the investment required to implement targeted awareness campaigns on energy efficiency and conservation at 20 select Mini-grid sites in Northern Uganda (Source: Author's elaboration)

#	Summary of Project implementation activities	Total Budget (USD)	Grant Budget (USD)	Contribution (USD)
A	Baseline activities	1,774	1,774	-
B	Remuneration costs & safety	27,688	25,941	1,747
C	Awareness activities	22,473	21,667	806
D	Capacity Building Sessions and handholding	56,452	48,360	8,091
E	Vendor mobilization & sample appliances	6,586	5,981	605
F	MEL and contingency	13,093	12,571	522
	TOTAL	128,066	116,294	11,772



1. Background/Context

Figure 2: Locations of the three mills assessed (Source: Google Earth)



Extending the electricity grid in Northern Uganda continues to pose significant challenges for the government due to the region's remote topography, dispersed settlements, and the high cost of extending the national grid. Northern Uganda has many districts, including Lamwo District, which is in the Acholi sub-region. Agriculture, particularly farming, is the backbone of the sub-region, where residents are heavily reliant on farming maize, cassava, simsim, and livestock.

The map in Figure 2 above shows Northern Uganda, including Lamwo District, where the mini-grid sites are located. Lamwo District is in Northern Uganda, and it borders South Sudan.

In 2021, the government of Uganda and its partners deployed solar mini-grids to address electricity access gaps and boost economic activity in Lamwo District. Due to the deployment of solar mini-grids, several productive-use enterprises, including grain milling, emerged.

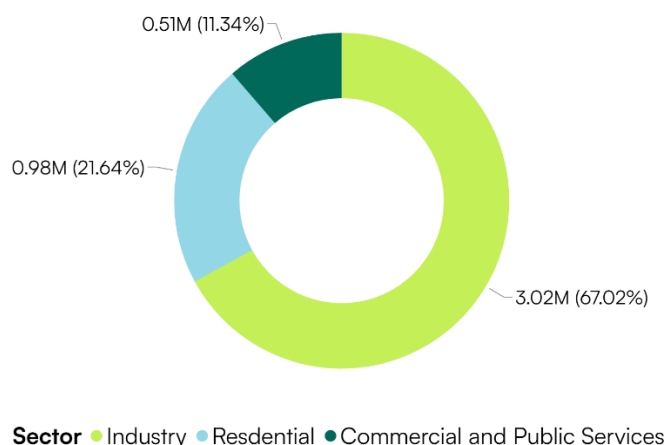
The grain mills have significantly enhanced local food security, generated income, created jobs, and become critical anchor loads for the solar mini-grids in Lamwo operated by NOA Uganda. Despite these gains, operational issues such as poor power quality, low-efficiency motors (including IEO and IE1 motors), and restricted operating hours for the grain mills (from 6:00 AM- 6:00 PM) remain due to mini-grids operating on batteries with limited capacity, which continues to affect enterprise productivity and the utilization of the solar mini-grids in Lamwo. In this regard, this study was conducted by a consortium between the Energy Efficiency Association of Uganda (EEAU) and the East African Center of Renewable Energy and Efficiency

(EACREEE), referred to in the report as the EEAU-EACREEE Consortium, by conducting preliminary energy audits at NOA Uganda Service mini-grid sites and load centers (including maize milling centers), following the ISO 50002-1:2025 Energy Audits. Part 1: General requirements with guidance for use to assess the grain milling electricity consumption pattern, technical performance, and socio-economic impacts, to identify targeted energy efficiency interventions that could lead to energy and cost savings, improve system reliability, sustainability, and increase development outcomes. Efficiency for Access, the implementing partner, CLASP, provided overall oversight of the project.

2. Introduction

Energy is a key cost driver in households, businesses, industries, and social institutions. Energy generation and utilization across sectors also contribute to overall carbon emissions. Therefore, investment in energy efficiency supports reducing avoidable energy costs, reducing energy-related carbon emissions, enhancing comfort and health in the built environment, and reducing overall energy demand by end users. Energy Efficiency is therefore a first fuel, alongside available renewable energy sources of hydropower, sustainable biomass, solar, geothermal, and wind.

Figure 3: Electricity (kWh) final consumption by sector, Uganda, 2023 (Source: Author's elaboration)



However, scaled adoption and investment in energy efficiency remain limited; this project therefore aims to assess the role of energy-efficient milling anchor load operations in supporting mini-grid deployments and accelerating energy efficiency in access projects. The project will focus on a case study of NOA's grain milling machines, deployed across 25 operational mini-grids in Northern Uganda, particularly in Lamwo District. The insights gained from this project will inform the design of more energy-efficient grain milling systems, enabling broader adoption across mini-grids and strengthening their long-term sustainability.

The study assessed NOA's mini-grids in Lamwo District by examining grain milling operations, the primary productive-use assets in the Mini-grid deployments. The research team conducted site visits at NOA-specified representative locations to assess current use of milling equipment and interview operators and users to identify operational problems. The research data will enable the development of a

technical framework that integrates high- or premium-efficiency motors with anchor loads (milling) to enhance system reliability and operational durability based on findings. The research will focus on deliverables highlighted in the key activities section.

Furthermore, the study examines the socio-economic impact of energy efficiency on the performance of mini-grids and grain-milling machines. The study responds to a recognized evidence gap: while solar mini-grid deployment across remote and post-conflict areas of Uganda has expanded rapidly, the relationship between the electrical performance of productive-use equipment (PUE), specifically grain-milling motors, and downstream household and enterprise welfare outcomes remains poorly quantified. This report synthesizes available operational data from the 3 NOA Lamwo mini-grid sites, along with published literature and sector benchmarks, to establish the baseline.

Lamwo District sits in the West Nile/Acholi border corridor, characterized by high post-displacement poverty (poverty headcount ~42%), predominantly subsistence agro-pastoralist livelihoods, and near-zero prior access to electricity. The district registered a Human Development Index (HDI) of approximately 0.39 (UNDP Uganda 2023), placing it among Uganda's five most energy-deprived districts. Grain milling is the single largest income-generating activity for both enterprises and households connected to NOA's mini-grid network, making motor performance a direct determinant of economic welfare.

NEoT Offgrid Africa (NOA), an investment platform designed to support Africa's energy transition by addressing energy access challenges, is a global, off-grid renewable energy developer, technology designer, and integrator. The company focuses on Renewable Energy and Energy Efficiency projects in Sub-Saharan Africa. With Remote Power Units (RPU), NOA provides a clean energy solution to 840 million people worldwide who lack access to electricity. Founded in 2008, NOA Uganda is currently owned by NOA. NOA Uganda Services has taken deliberate, targeted steps to promote the Productive Use of Electricity (PUE), ensuring that access to electricity translates into real economic opportunities for customers and communities. Below is a summary of the key activities initiated and the impact recorded to date.

A. Activities Initiated by NOA Uganda

i. Appliance Distribution and Facilitation

NOA has facilitated the deployment of a wide range of productive-use appliances targeting small and micro-enterprises across different sectors. These include:

- Food and beverage equipment: popcorn machines, deep fryers, juice blenders, juice dispensers, electric kettles, and electric pressure cookers
- Cooling and preservation equipment: chest freezers
- Salon and personal care tools: hair clippers, towel warmers/sterilizers, and flat irons
- Business equipment: printers and charging boxes/systems
- Industrial machinery: welding machines, angle grinders, and electric motors

The selection of these appliances has been deliberately aligned with the income-generating activities most prevalent among NOA's customer base, ensuring relevance and impact.

ii. Pilot Programs and Feasibility Studies

NOA has partnered with Customized Energy Solutions (CES) to pilot single-phase maize mills over three months. This allows customers to evaluate their performance against the more common three-phase mills and determine the most efficient and cost-effective option. In parallel, feasibility studies and pilot deployments of electric pressure cookers have been undertaken to assess their efficiency, cost savings, and adoption potential among target users.

iii. Customer Identification and Mobilization

Through dedicated field teams, NOA has proactively identified and mobilized potential PUE customers, particularly SMEs. These engagements focus on understanding customer business needs and matching them with appropriate appliances. Priority segments include shop owners, agro-processors, welders, and salon operators.

iv. Community Sensitization and Awareness Campaigns

NOA has conducted outreach activities across trading centers and refugee settlements, demonstrating how electricity can power businesses and generate income. Practical, real-world demonstrations of appliances have enabled potential users to understand both their functionality and economic value clearly. Campaigns have also been strategically timed to coincide with peak business periods such as festive seasons to maximize relevance and uptake.

v. Strategic Partnerships

Two key partnerships have been instrumental in scaling PUE activities:

1. VisionFund Microfinance Partner

This partnership enables customers to access affordable credit with flexible repayment terms, directly addressing affordability barriers to appliance acquisition.

2. CEI Grant Support

This grant has enabled NOA to:

- Deploy appliances at subsidized prices, improving accessibility
- Deliver structured capacity-building and training sessions before deployment, ensuring customers are technically

equipped to use appliances effectively and sustainably

B. Impact to Date by NOA Uganda

The above interventions have generated the following outcomes:

i. Increased Appliance Uptake

A growing number of small businesses across food vending, salons, welding, and agro-processing have adopted productive use appliances, improved efficiency, and expanded service offerings.

ii. Improved Customer Awareness

Communities now have a stronger understanding of electricity as a tool for business and income generation, beyond basic lighting.

iii. Growth in Small Business Activity

Beneficiaries have diversified and expanded their services, including cold storage, food processing, phone charging, and metal fabrication, thereby improving household incomes.

iv. Enhanced Access Through Financing

Credit support from VisionFund and subsidized pricing through CEI have enabled more customers, especially those previously constrained, to participate in PUE activities.

v. Increased Electricity Demand

Productive use of appliances has led to higher, more consistent electricity consumption among customers, supporting the network's financial sustainability.

vi. Evidence-Based Learning

Ongoing pilot programs, particularly the maize mill initiative, are generating valuable insights

Objective of the Study

The main objective is to determine the effect of prioritizing energy-efficient motors and energy-efficiency practices for anchor loads (milling) as the primary focus in Mini-grids, and how this promotes access and a business case for Mini-grids.

3. Literature Review

EEAU-EACREEE Consortium conducted a literature review of relevant documents to obtain information on motors, energy efficiency, and mini-grids.

Mini-grids are sets of electricity generators and, possibly, energy storage systems interconnected to a distribution network that supplies electricity to a localized group of customers. They involve small-scale electricity generation (10 kW to 10MW) which serves a limited number of consumers via a distribution grid that can operate independently of national electricity transmission networks. They are a reliable, flexible, and cost-effective way to provide clean energy access to underserved regions. They are among the key solutions to the challenge of electricity access in rural areas in Uganda. There are initiatives from the government, development partners, and the private sector in driving electricity access. Lamwo District is a strategic district for mini-grid development because the area's main activity is agriculture and it hosts about 79,238 refugees (as of June 2023). The energy access

on cost-effectiveness, customer preferences, and technology performance, informing future scale-up decisions.

agenda in Uganda aims to achieve universal energy access by 2040².

The majority of the refugees are from South Sudan and live in the Palabek Ogili Sub-County. GlZ's Pro-Mini Grid Program implemented 25 mini-grids in Lamwo District, Northern Uganda in 2022, and all sites are operational, serving over 3,000 households and 1,000 business units, providing reliable, accessible electricity.

In Uganda, there are currently 46 established mini-grids, 41 under implementation, and 166 mini-grids already planned for implementation with committed funding. Following the success of the Pro Mini-grids Project, another project, GET Access Uganda was implemented with funding of 35 million Euros from the European Union (EU) and Germany in 2021³. On the 21st of April, the President of Uganda assented to the Energy Efficiency and Conservation Act 2026, which reflects the government's commitment to promoting energy efficiency and conservation interventions in Uganda's energy sector. This single act has positive ripple-effect implications across the entire sector, accelerating the adoption of energy-efficiency and conservation interventions nationwide.

¹ [Policies and Regulations for Private Sector Renewable Energy Mini-grids](#)

² https://energypedia.info/wiki/Mini_Grids

³https://www.eeas.europa.eu/delegations/uganda/powering-rural-uganda-eu-support-mini-grid-developments_en

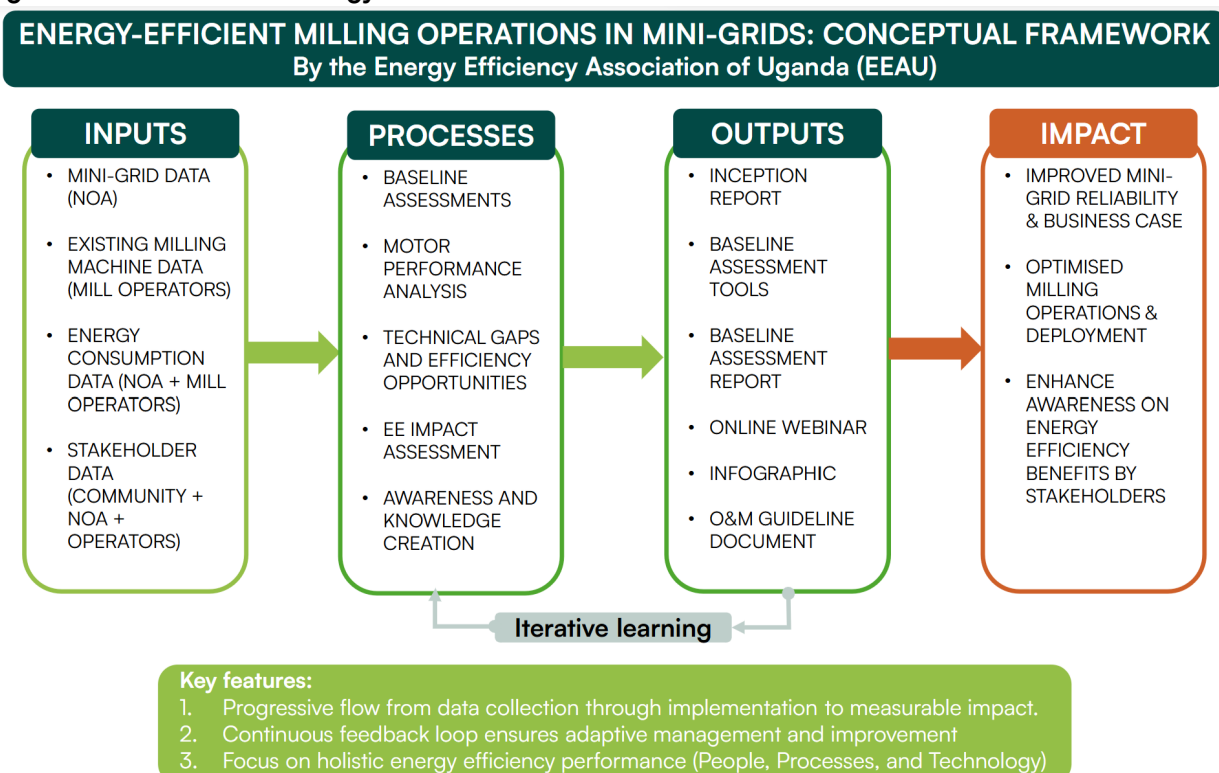
4. Methodology

This study adopts a structured approach to gain insights into the energy consumption patterns of solar mini-grids powering grain milling in Northern Uganda. The methodology involved a data-driven assessment of three grain millers and key informant interviews with nine stakeholders. The figure below shows the type of data collected.

Figure 4: Data Collection Strategy for the Project



Figure 5: Detailed Methodology



The EEAU-EACREEE Consortium used a cross-sectional study design, collecting both quantitative and qualitative data.

Questionnaires were developed and used for quantitative data collection, while key informant guides were used for qualitative data collection. Quantitative data were collected from three grain millers, and qualitative data were collected from nine stakeholders, as indicated above.

The EEAU-EACREEE Consortium conducted preliminary energy audits at the mini-grid sites and load centers (including maize milling centers) in accordance with ISO 50002-1:2025, Energy Audits, Part 1: General requirements with guidance for use. The following indicates the energy audit process.

The tasks for the study include the following;

Task 1: Conduct a technical performance assessment for motors used by anchor loads in mini-grid areas.

Task 2: Conduct a study to assess the impact of energy efficiency on mini-grid and Grain Milling Machine performance.

Task 3: Develop a webinar and an infographic publication presenting insights

on mini-grid design, integrating energy efficiency, and the effects of inefficiency on mini-grid operation.

Task 4: Develop a motor efficiency and energy management guideline document from the findings.

Task 5: Develop a final project report that covers all tasks and their activities. This study report covers Tasks 1 and 2.

Task 1: Conduct a technical performance assessment for motors used by anchor loads in mini-grid areas.

Motor assessment and performance

The EEAU-EACREEE Consortium developed a template for collecting baseline energy data from mini-grid sites and anchor loads (including grain mills). This data was used to establish a benchmark against which measured energy data can be compared to indicate the energy efficiency of equipment and systems.

Energy measurements were conducted using energy audit equipment to ascertain the current energy consumption. Key energy equipment included a Power Quality Analyzer, Energy and Power Loggers, a Thermographic Camera, and a Tachometer.

Figure 6: Energy Audit Process (Source: Government of Nepal, Water and Energy Commission Secretariat)

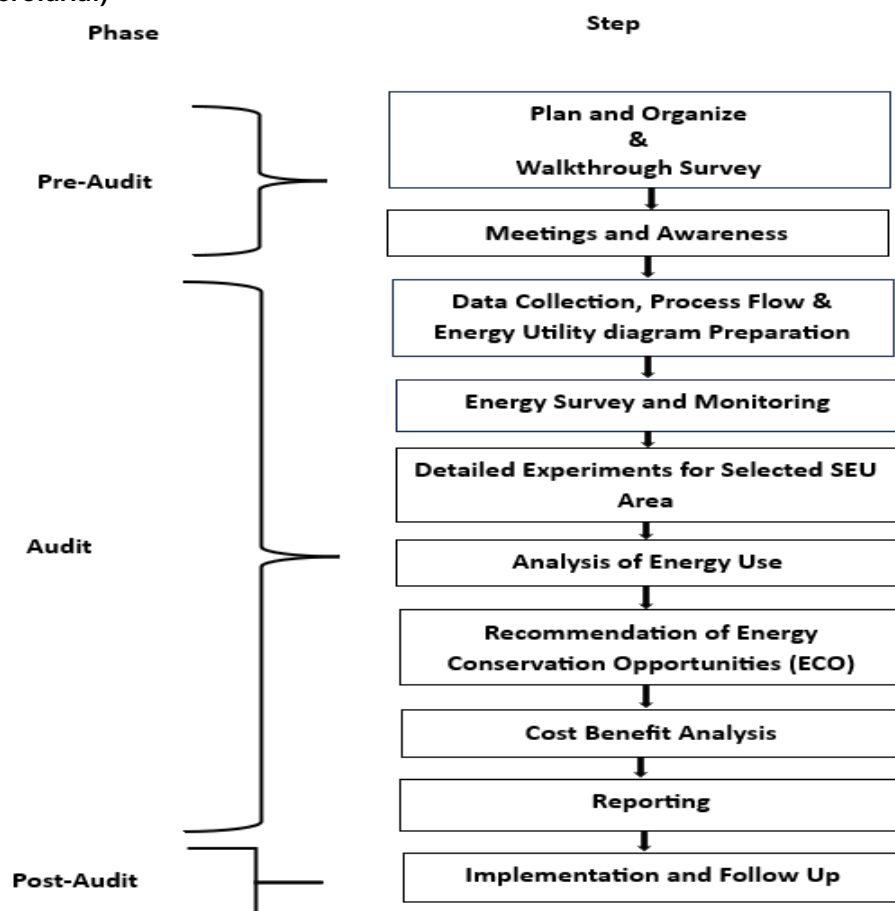


Table 2: Energy Audit Equipment (Source: Author's elaboration)

Name	Data Parameters	Picture
Power Quality Analyzer (PQA)	Voltage, Current, Reactive Power, Real Power, and Frequency	

Energy Logger	Voltage (V), Current (A), Active Power (kW), Apparent Power (kVA), Reactive Power (kVAR), Power Factor (PF), Energy Consumption (kWh), Frequency (Hz), Voltage/Current imbalance, Harmonics	
Thermographic Camera	Surface Temperature (°C), Thermal Image	
Tachometer	Rotational Speed (RPM) (Minimum RPM, Maximum RPM, Average RPM)	

Task 2: Conduct a study to assess the impact of energy efficiency on mini-grid and Grain Milling Machine performance.

The EEAU-EACREEE Consortium conducted a literature review of secondary data on energy efficiency, Mini-grids, and maize milling performance, including policies, regulations, case studies, publications, and reports. The consultant used field-obtained energy data and conducted energy measurements with the energy audit equipment. The consortium analyzed the collected data and produced the baseline assessment report.

To complement the quantitative baseline, this report draws on Key Informant Interviews (KIIs) from stakeholders and one multi-stakeholder briefing conducted by research

teams from the Energy Efficiency Association of Uganda (EEAU) and the East African Center of Excellence for Renewable Energy and Efficiency (EACREEE) between 23 April and 20 May 2026. These respondents are profiled in Section 3. This was done to cross-check what people on the ground experience.

The nine Key Informant Interviews and one multi-stakeholder briefing across the NOA Lamwo service area included the energy-consuming millers, NOA technical and commercial staff, village representatives, equipment suppliers, and district officials. Energy-consumer interviews were conducted under the assurance of confidentiality.

Table 3: KII Profile (Author's elaboration)

Code	Respondent Profile	Location
M-01	Miller (energy consumer), male	NOA mini-grid site, Lamwo
M-02	Miller (energy consumer), male	NOA mini-grid site, Lamwo
M-03	Miller/community member, male	Otaa Village, Lamwo
TECH-01	NOA technician, with brief input from NOA commercial and management staff	Lamwo District
VR-01	NOA village representative, male	Apyetta Trading Center, Lamwo
SUP-01	Equipment supplier (industrial electricals), female	Kampala
SUP-02	Equipment suppliers (cables, earthing, solar hardware), male, two respondents	Kampala
NOA-OPS	NOA operations team: Country Director, commercial representative, technician/manager	Northern Region, Uganda
DIST-01	District officials, village representatives and researchers (stakeholder engagement)	Lamwo District

3. Study Findings and Key Insights

As solar mini-grids increasingly serve as the backbone of rural electrification in Northern Uganda, understanding how productive-use enterprises consume and interact with electricity becomes critical to improving system performance and socio-economic outcomes. The findings presented in this section draw on metered energy data and stakeholder interviews to provide granular evidence on electricity consumption patterns, motor performance, operational practices, and power-quality challenges among mini-grid-powered grain mills. There is a case for energy efficiency and energy conservation in

The EEAU-EACREEE Consortium team conducted site visits in Lamwo District from 22nd April 2026 to 29th April 2026. The team conducted energy measurements at 3 sites in Lamwo and conducted Key Informant Interviews with the District Local Government, 3 millers, 2 energy equipment suppliers, and three of NOA's critical team members.

Mini-Grid Performance

The table below shows the installed capacity of the three solar mini-grid sites visited in Lamwo District, Northern Uganda.

increasing mini-grid reliability and sustainability while enhancing the economics and sustainability of milling operations

Table 4: Description of the three mini-grid sites in Lamwo District, Northern Uganda (Source: NOA)

Description	Mini Grid Site A		Mini Grid Site B	Mini Grid Site C
Location in Lamwo	Ogili TC		Muddu Central TC	Apyetta TC
Milling Customer	Customer #1-Mill	Customer #2-Mill	Customer #3-Mill	None Evaluated
Grain milling machines' average consumption per month (kWh)	251.8	178.26	240.31	0
Mini-grid load factor	28.60%		39.80%	36.16%
Mini-grid Solar Size (kWp)	80		40	40
Battery Size (kWh)	288		144	144
Monthly solar generation (kW)	9,136		4,568	4,568
Monthly consumption (kWh)	2,681		573	2,083
Business average customers per month	25.06		74.1	16.62
Household average customers per month	14.95		10.82	13.21
Mini-grid utilization rate	29%		13%	46%
SAIDI	35		N/A	217
SAIFI	9		N/A	47
CAIDI	233		N/A	319

Mini-Grid reliability

The Mini-Grid Reliability for each site was calculated using a modified formula for SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), and CAIDI (Calculated Average Interruption Duration Index), as shown below, based on available inverter data on voltage and frequency. The formula was updated since it is assumed that the outages shown in the data affect all customers and not a few customers, as is the usual case with SAIDI and SAIFI calculations, because the data provided was Mini-Grid site data and not customer-metered data, as the former is not available due to a change in metering system for all customers. The momentary interruption allowed is 60 minutes for all calculations. For

comparison, and in accordance with ERA regulations and NOA's Technical team, the recommended SAIDI levels for Mini-Grid sites are 70% reliability (16.8 hours per month) and 90% reliability (approximately 21.6 hours per month). Below are the SAIDI, SAIFI, and CAIDI values for the Ogili site.

$$\text{SAIDI} = \frac{\Sigma(\text{No. Customers affected} \times \text{duration})}{\text{Total No. of Customers}} = \Sigma \text{duration (minutes/customer)} \dots\dots\dots 1$$

$$\text{SAIFI} = \frac{\Sigma(\text{No. Customers affected})}{\text{Total No. of Customers}} = \text{Events (interruptions/customer)} \dots\dots\dots 2$$

$$\text{CAIDI} = \frac{\text{SAIDI}}{\text{SAIFI}} = \text{average duration per interruption (min/interruption)} \dots\dots\dots 3$$

Using the above formulae and with the support of Claude AI, the next section provides the SAIDI, SAIFI, and CAIDI values for the Ogili and Apyetta Mini-Grid sites for which substantial detailed data were available. Data for Muddu Central was unavailable and therefore not considered.

OGILI MINI-GRID RELIABILITY

For the Ogili Mini-Grid site, the SAIDI, SAIFI, and CAIDI values are shown in the tables and figure below. From the first table, the data reveal a SAIFI of nine (9) critical power outage events, two of which are typical energy-related events attributed to system outages due to limitations in system storage capacity that NOA is aware of, and seven (7) others related to unplanned outages. The second table details each outage, when it started and ended, and its duration. The figure below is a heatmap showing all the unplanned outages at the Mini-grid site.

Table 5: Summary of the SAIFI, SAIDI, and CAIDI values for Ogili mini-grid site in Lamwo District, Northern Uganda (Source: NOA)

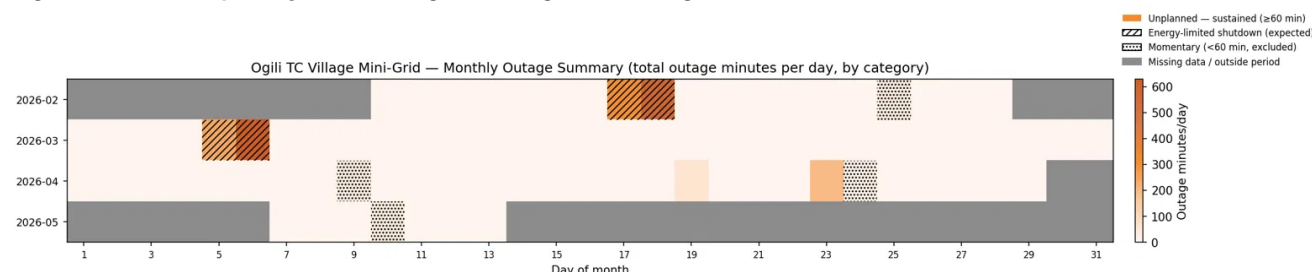
Category	SAIFI	SAIDI	CAIDI
Unplanned only	7	360 min (6.0 h)	51.4 min
Unplanned and Energy-limited (expected)	2	1,740 min (29.0 h)	870.0 min
All combined	9	2,100 min (35.0 h)	233.3 min

Table 6: Details of the system outages for Ogili mini-grid site in Lamwo District, Northern Uganda (Source: Author's elaboration)

#	Start	End	Duration
1	2026-02-17 19:00	2026-02-18 09:30	14h 30m
2	2026-02-25 11:00	2026-02-25 11:30	0h 30m
3	2026-03-05 20:00	2026-03-06 10:30	14h 30m
4	2026-04-09 08:45	2026-04-09 09:15	0h 30m

5	2026-04-19 18:00	2026-04-19 19:00	1h 0m
6	2026-04-23 14:15	2026-04-23 17:30	3h 15m
7	2026-04-24 18:45	2026-04-24 19:00	0h 15m
8	2026-05-10 15:00	2026-05-10 15:15	0h 15m
9	2026-05-10 17:45	2026-05-10 18:00	0h 15m

Figure 7: Heatmap of system outages for Ogili TC Village Mini-Grid



From the tables and Figure above, it is evident that the SAIDI values of Ogili Site are relatively high considering the recommended levels; this indicates a need for the mini-grid developer to consider enhancing the system capacity levels and energy efficiency for the end-users, as the largest contribution to SAIDI is attributed to two events categorized as energy-limited interruptions or shutdowns, which are actually attributed to energy consumption beyond the capacity of the system in February and March with identical durations of 14 hours 30 minutes each or 1740 minutes/day outage. Energy efficiency that reduces end-use energy consumption could provide a relative advantage in reducing energy use and, in turn, system outages attributed to energy-limited interruptions. It is worth noting that the data for the site, as shown in the figure above, specifically the 6-week Dec 30th to Feb 9th span and the 30th Apr to 3rd May span, have no usable telemetry and therefore present significant gaps that affected the quality of the output; however, these data gaps are known to the NOA team.

APYETTA MINI-GRID RELIABILITY

For the Apyetta Mini-Grid site, the SAIDI, SAIFI, and CAIDI values are shown in the tables and figure below. From the first table, the data reveals a SAIFI of forty-four (44) critical power outage events, all considered typical energy-related events attributed to system limitations in capacity that NOA is aware of, three of which were momentary unplanned outages. The second table details each outage, when it started and ended, and its duration.

Table 7: Summary of the SAIFI, SAIDI, and CAIDI values for Ogili mini-grid site in Lamwo District, Northern Uganda (Source: NOA)

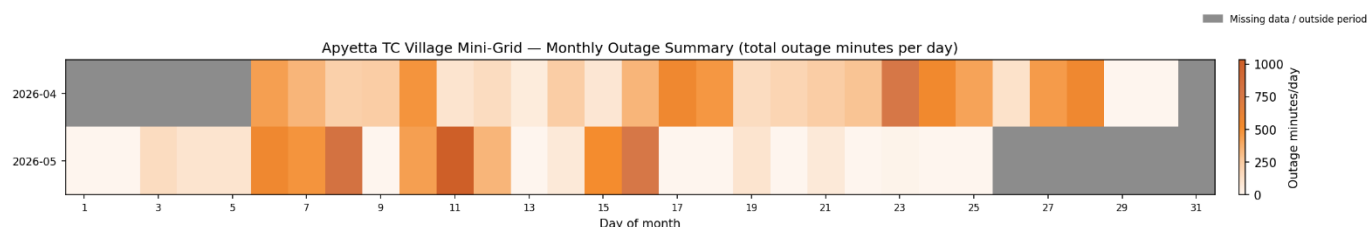
Category	SAIFI	SAIDI	CAIDI
Unplanned only (> 60 mins)	44	12,960 min (216.0 h)	294.5 min
Unplanned monetary (< 60 min)	3	75 min (1.25 h)	25.0 min
All combined	47	13035 min (217.25 h)	319.5 min

Table 8: Details of the system outages for Ogili mini-grid site in Lamwo District, Northern Uganda
(Source: Author's elaboration)

#	Start	End	Duration
1	2026-04-06 00:15	2026-04-06 06:15	6h 0m
2	2026-04-06 08:00	2026-04-06 09:15	1h 15m
3	2026-04-07 02:15	2026-04-07 06:15	4h 0m
4	2026-04-07 07:30	2026-04-07 09:15	1h 45m
5	2026-04-08 02:30	2026-04-08 06:15	3h 45m
6	2026-04-09 04:30	2026-04-09 06:15	1h 45m
7	2026-04-09 07:45	2026-04-09 09:15	1h 30m
8	2026-04-09 23:15	2026-04-10 06:15	7h 0m
9	2026-04-10 07:30	2026-04-10 09:15	1h 45m
10	2026-04-11 04:30	2026-04-11 06:15	1h 45m
11	2026-04-12 03:45	2026-04-12 06:15	2h 30m
12	2026-04-13 05:15	2026-04-13 06:15	1h 0m
13	2026-04-14 02:15	2026-04-14 06:15	4h 0m
14	2026-04-15 04:45	2026-04-15 06:15	1h 30m
15	2026-04-16 02:30	2026-04-16 06:15	3h 45m
16	2026-04-16 22:00	2026-04-17 06:15	8h 15m
17	2026-04-17 06:30	2026-04-17 09:15	2h 45m
18	2026-04-17 23:45	2026-04-18 06:15	6h 30m
19	2026-04-18 07:45	2026-04-18 09:15	1h 30m
20	2026-04-19 03:45	2026-04-19 06:15	2h 30m
21	2026-04-20 03:00	2026-04-20 06:15	3h 15m
22	2026-04-21 02:15	2026-04-21 06:15	4h 0m
23	2026-04-22 03:00	2026-04-22 06:15	3h 15m
24	2026-04-22 22:30	2026-04-23 06:15	7h 45m
25	2026-04-23 06:45	2026-04-23 11:30	4h 45m
26	2026-04-23 22:15	2026-04-24 06:15	8h 0m
27	2026-04-24 06:45	2026-04-24 09:15	2h 30m
28	2026-04-24 15:30	2026-04-24 15:45	0h 15m
29	2026-04-25 01:00	2026-04-25 06:15	5h 15m
30	2026-04-25 07:30	2026-04-25 09:15	1h 45m
31	2026-04-26 04:15	2026-04-26 06:15	2h 0m
32	2026-04-27 03:15	2026-04-27 06:15	3h 0m
33	2026-04-27 19:30	2026-04-28 09:15	13h 45m
34	2026-05-03 03:45	2026-05-03 06:15	2h 30m
35	2026-05-04 04:30	2026-05-04 06:15	1h 45m
36	2026-05-05 22:15	2026-05-06 09:15	11h 0m
37	2026-05-07 16:00	2026-05-08 06:30	14h 30m

38	2026-05-08 11:45	2026-05-08 19:00	7h 15m
39	2026-05-10 16:45	2026-05-11 11:00	18h 15m
40	2026-05-11 13:30	2026-05-11 19:45	6h 15m
41	2026-05-12 15:00	2026-05-12 20:45	5h 45m
42	2026-05-14 05:00	2026-05-14 06:15	1h 15m
43	2026-05-15 15:30	2026-05-16 12:45	21h 15m
44	2026-05-19 05:30	2026-05-19 06:15	0h 45m
45	2026-05-19 08:15	2026-05-19 09:15	1h 0m
46	2026-05-21 05:00	2026-05-21 06:15	1h 15m
47	2026-05-23 06:00	2026-05-23 06:15	0h 15m

Figure 8: Heatmap of system outages for Apyetta TC Village Mini-Grid:



From the tables and Figure above, it is evident that the SAIDI values of Apyetta site are very high considering the recommended levels; this indicates a need for the mini-grid developer as seen with Ogili Site to consider enhancing the system capacity levels and energy efficiency for the end-users, as the largest contribution to SAIDI is attributed to more than 45/47 events can be categorized as energy-limited interruptions or shutdowns due to the time frame in which they occur 16:45 to 09:15 hours, which are actually attributed to energy consumption beyond the capacity of the system in April and May. Energy efficiency that reduces end-use energy consumption could provide a relative advantage in reducing energy use and, in turn, system outages attributed to energy-limited interruptions. It is worth noting that the data for the site, as shown in the figure above, specifically the 6-week data for January, February, and March, have no usable telemetry and therefore present significant gaps that affected the quality of the output; however, these data gaps are known by the NOA team.

Energy Consumption

Muddu Central Grid Site Consumption versus Generation

The data on energy generation from the Muddu Central mini-grid site from January 2022 to March 2026 are shown in the figure below. The highest energy generated at the site was 19,200 kWh in 2024, and there were periods without power generation, including the whole of 2025 and January to March 2026.

Ogili Mini-Grid Site Consumption versus Generation

The figure below shows the annual energy generation and consumption for the Ogili mini-grid site. The highest energy generated was 77,000 kWh, with consumption at 33000 kWh in 2025. The highest energy consumption, however, was in 2026 at 40,000 kWh. The figure shows a noticeable change in the energy performance of the Ogili Trading Center between January 2025 and March 2026. The Mini-Grid generation remains relatively stable, averaging 6,060 kWh and peaking at 6,900 kWh in 2025, before plummeting to 2,400 kWh in March 2026. Periods of severe energy generation crashes can be attributed to the rainy season, when sunshine is limited.

Apyetta Mini-Grid Site Consumption versus Generation

The figure below shows the annual energy generation and consumption for the Apyetta mini-grid site. The highest energy generated was 4,267 kWh, with consumption at 2,294 kWh in 2025. The highest energy consumption, however, was in 2026 at 2,532 kWh.

Across all sites, there are instances where generation and consumption are equal or where consumption exceeds generation for example in Muddu Central in the period from June 2023 to December 2023, Ogili in period between July 2023 and August 2023 and in Apyetta TC between December 2022 to February 2023 the, indicating capacity constraints that require attention and for which energy efficiency and conservation could help ensure better system reliability and sustainability over the long haul.

Figure 9: Annual Generation and Consumption Profile for Muddu Trading Centers (TC) Mini-Grid in Lamwo District (Source: Author’s elaboration)

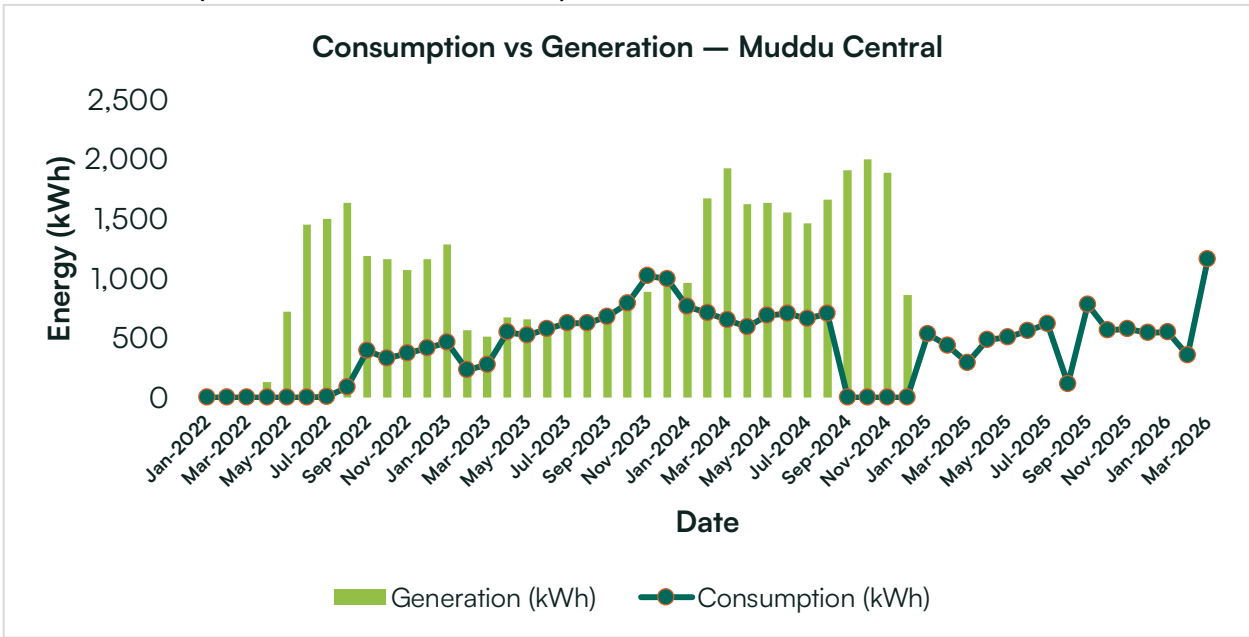


Figure 10: Annual Generation and Consumption Profile for Ogili Trading Centers (TC) Mini-Grid in Lamwo District (Source: Author's elaboration)

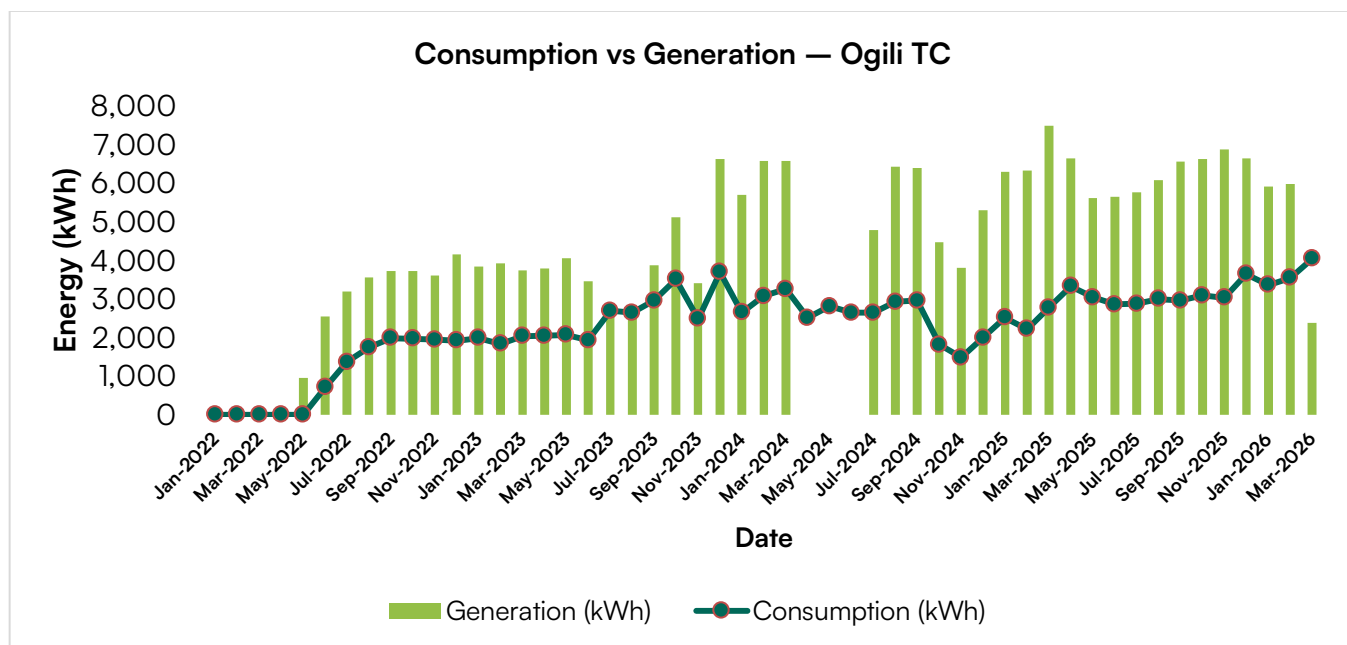


Figure 11: Annual Generation and Consumption Profile for Apyetta Trading Centers (TC) Mini-Grid in Lamwo District (Source: Author's elaboration)

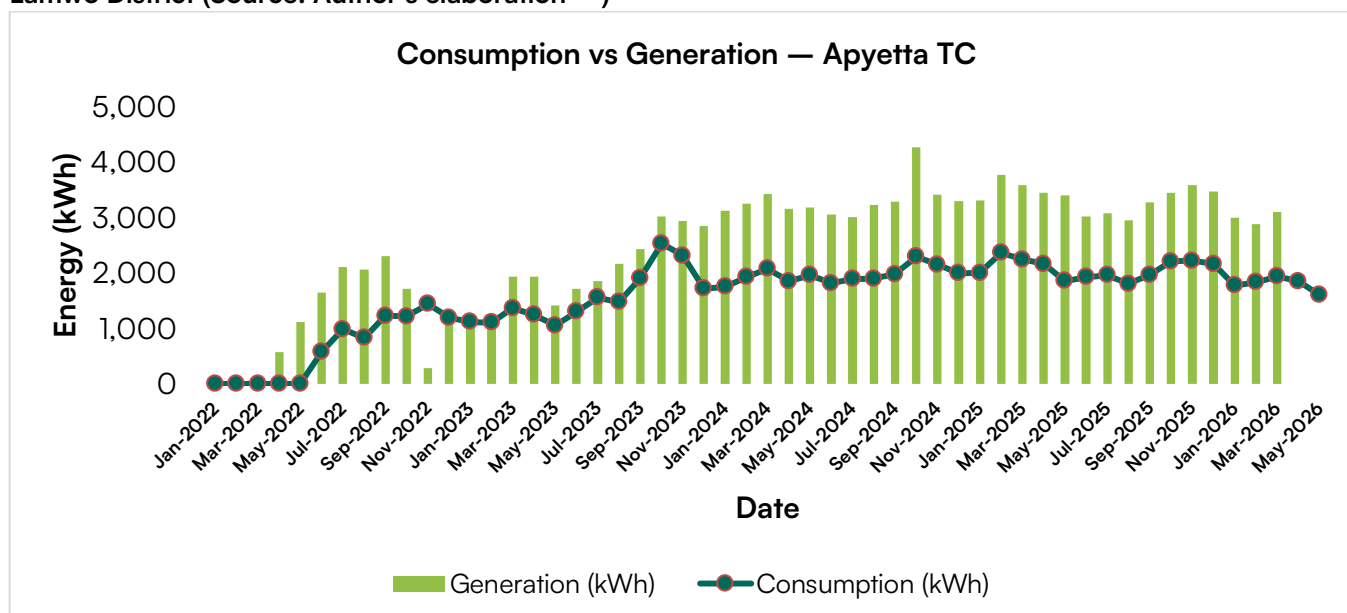
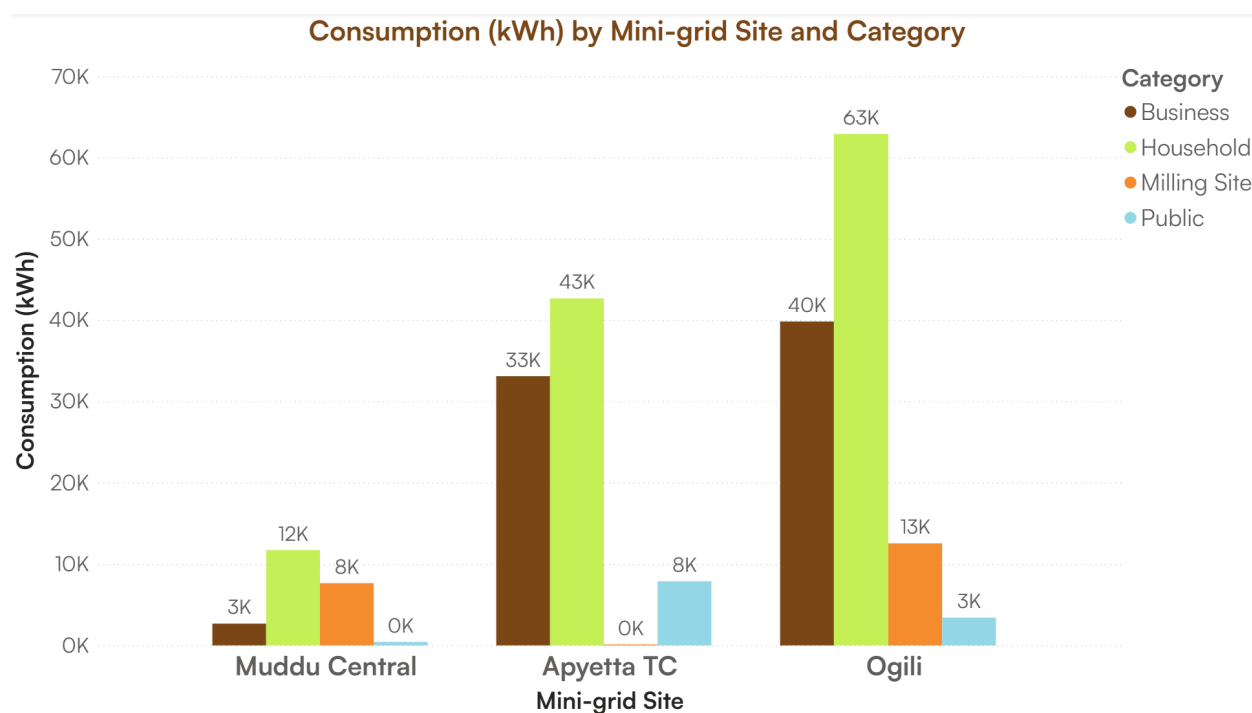


Figure 12: Distribution of Customer Category by Mini-Grid Site (Source: Author's elaboration)



Ogili Trading Center Consumption by Category

In the figure above, at Ogili Trading Center, milling sites account for only 10.59% (13 MWh) of overall energy consumption, with households taking the lion's share at 52% (63 MWh). Businesses recorded the second highest consumption (40MWh). Public institutions recorded the lowest electricity consumption, estimated at 3 MWh, indicating limited connectivity in schools, health facilities, and other public institutions.

Muddu Central Trading Center Consumption by Category

As shown in the figure above, like Ogili Trading Center, households consume most of the electricity generated by the Mini-Grid (52.09%, totaling 12 MWh). The milling sites followed suit, with consumption beginning at 12 MWh (34.04%). Business came third in the ranking, with consumption of 3MWh (11.92%). Public institutions accounted for the lowest consumption (1.95%).

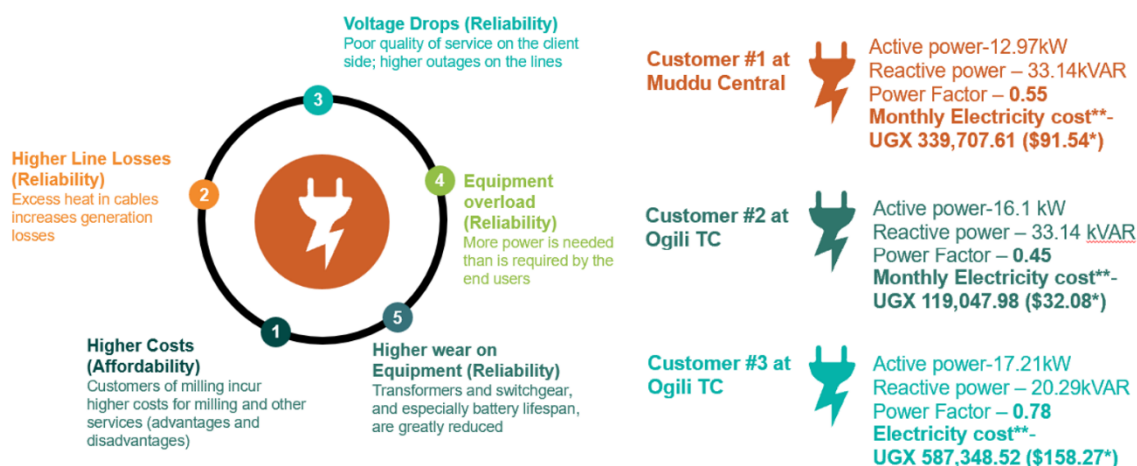
Apyetta Trading Center Consumption by Category

Households consume most of the electricity generated by the Mini-Grid at Apyetta TC (50.99%, totaling 63 MWh). Businesses followed with about 33 MWh (39.29%). Public institutions, unlike those in the other trading centers, have recorded noticeable consumption (8 MWh, or 9.72%), indicating that education and health facilities, among other public institutions, are connected to the Mini-Grid. Grain milling operations are non-existent in Apyetta Trading Center.

Energy Measurements

The findings from the measurements, as shown below, indicate significant unintended consequences associated with inefficient energy milling operations, from poor power factor at each milling site to poor loading and inadequate maintenance practices, all combined to create higher energy costs for millers, who in actuality only pay for a small amount of generated energy increasing negative impacts on the Mini-Grid such line losses due as excess heat in cabling system attributed overloading, frequent voltage drops reducing the quality of service and reliability of the mini-grid connection to downstream customers, overloading of equipment increase wear increasing operation and maintenance costs to the Mini-grid. This picture reveals a need to enhance energy conservation and efficiency measures across the entire mini-grid ecosystem to reduce negative impacts, increase reliability, and improve the Mini-grid's sustainability in the medium and long term.

Figure 13: The negative impacts of inefficient energy milling operations at mini-grid sites in Northern Uganda (Source: Author's elaboration)



Power Measurements and Analysis for Customer #1 Milling Machines at Muddu Central Mini- Grid Site

The parameters reproduced in this section of the report are limited to customer milling machine data at Muddu Central and are considered relevant to this study for the logging period (30 days) at 1-minute recording intervals.

Figure 14: Fluke 1736 Installed at the Main Incomer of Customer #1's Milling Machine



The connection was performed in the measurement topology of the WYE Mode Three-Phase (3ϕ) 4 Wire system.

Power

The maximum recorded electrical measurement values were 12.97 kW for Active Power, 26.31 kVA for Apparent Power, and 23.76 kVAr for Reactive Power.

The Average power recorded was 8.309 kW, 9.872 kVA, and 7.955 kVAr for Active, Apparent, and Reactive Power, respectively.

Figure 15: Maximum Active Power, Apparent Power, and Reactive Power:

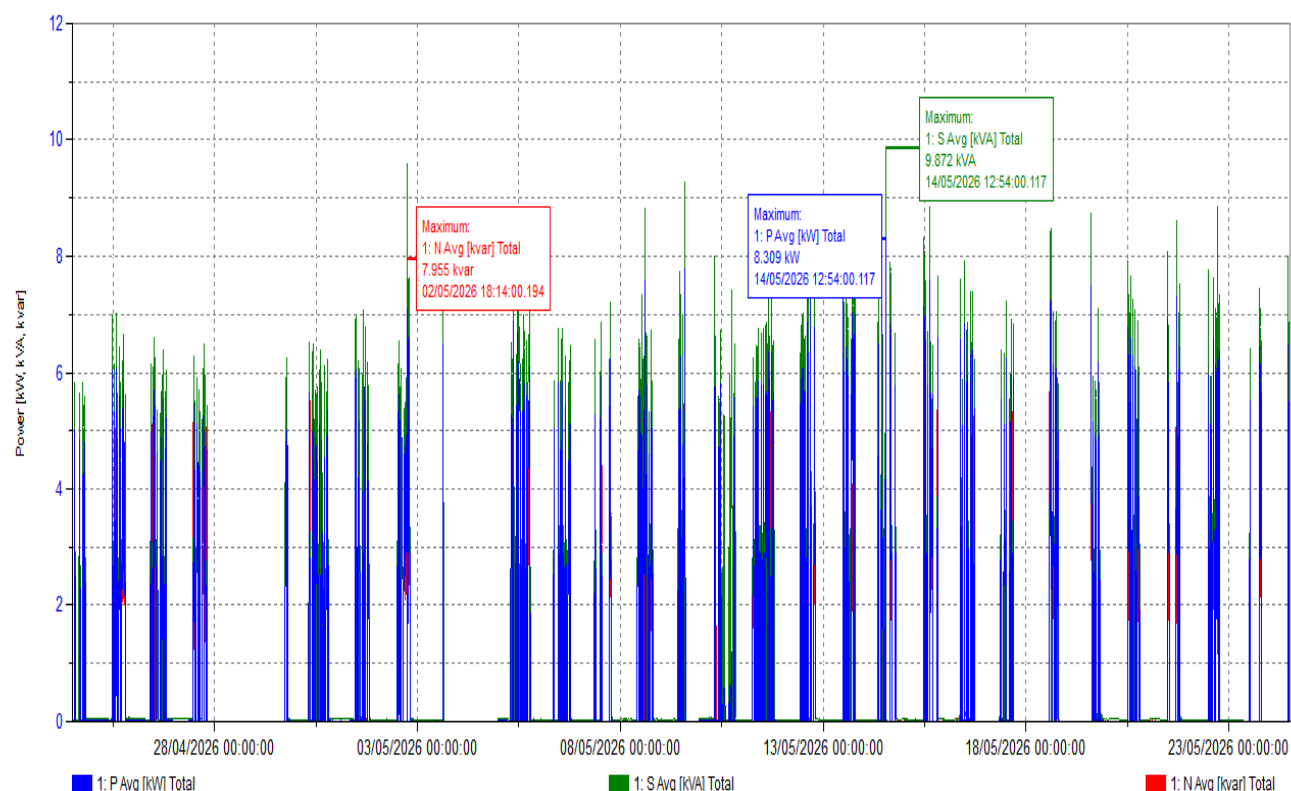


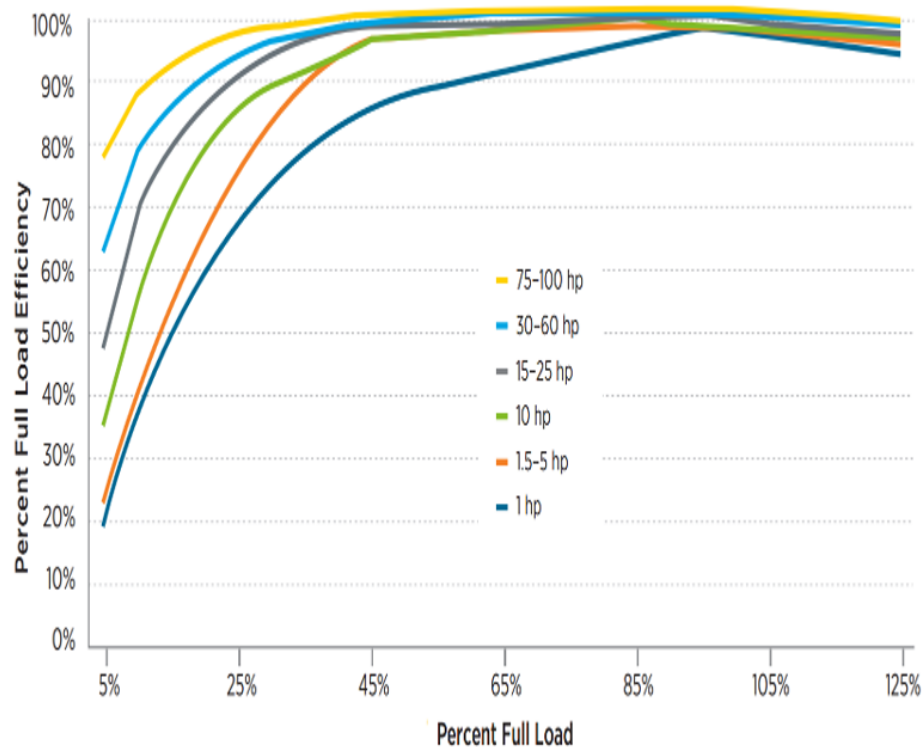
Table 9: Average and Maximum Power Recording

ID	Average Power	ID	Maximum Power
1	Average: 1: P Avg [kW] Total 8.309 kW 14/05/2026 12:54:00.117	4	Maximum: 1: P Max [kW] Total 12.972 kW 02/05/2026 18:14:00.194
2	Average 1: S Avg [kVA] Total 9.872 kVA 14/05/2026 12:54:00.117	5	Maximum: 1: S Max [kVA] Total 26.312 kVA 30/04/2026 08:08:00.129
3	Average: 1: N Avg [kVAr] Total 7.955 kVAr	6	Maximum: 1: N Max [kVAr] Total 23.763 kVAr

Power factor

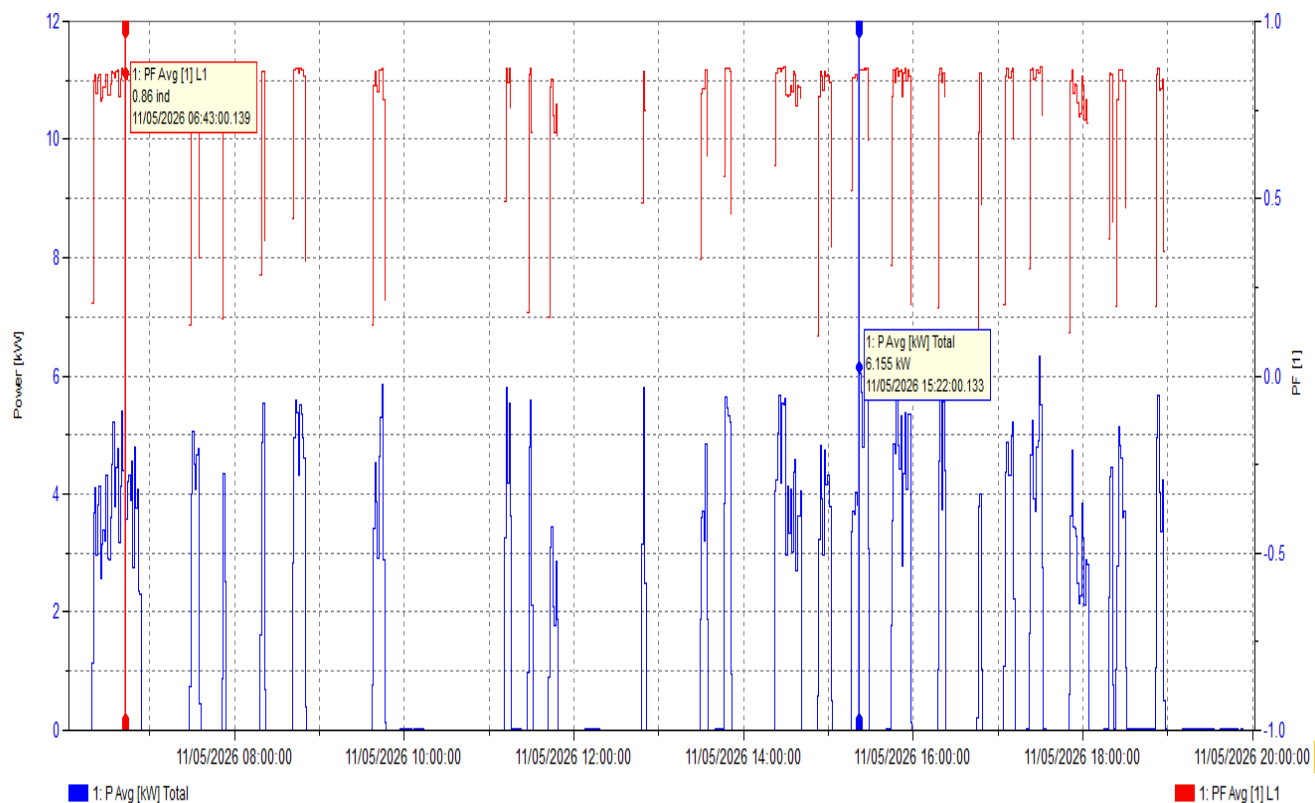
The Maximum average power factor recorded during the measurement was 0.86, and the minimum was 0.4. The figure below shows the trend of a typical one-day operation in measuring power and power factor. This is the typical case seen across all milling customers assessed. The acceptable power factor range is 0.94 to 0.98, which was not observed at any of the measured sites. For motors assessed, the millers indicated ranges of between 2-10 Kg/day milling, which is much less than the 75-85% motor loading, which translates to between 300 kg and 500 kg (crushing), 250 — 350 kg (fine flour) of maize per hour expected for motors deployed at the milling sites, translating to the very large variance in power factor, attributed to this poor motor loading, which worsens power factor and lowers efficiency, leading to unintended consequences. As shown in the figure below, regardless of motor size (1HP-100HP), if the percentage load is below 25% of the full rated load, the power factor deteriorates exponentially, along with motor efficiency.

Figure 16: Typical expected load profile for different motor sizes versus efficiency⁴



⁴ <https://eec.oregonstate.edu/oversized-motors>

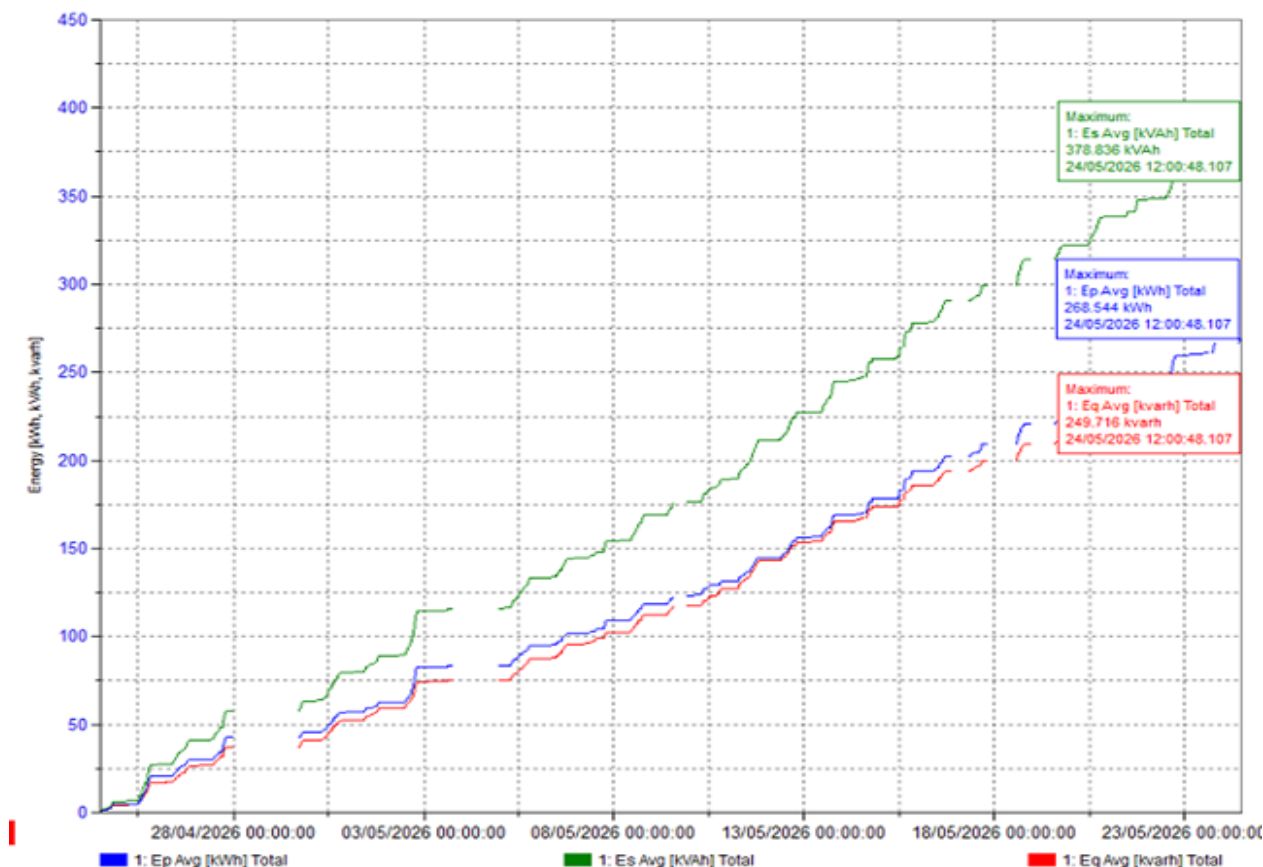
Figure 17: Typical One-Day RMS Average Power and Power Factor Trend



Energy consumption

After 30 days of logging into Customer #1's milling machine, the maximum total active energy consumed at the facility was 268.53 kWh, the maximum total apparent energy was 378.83 kVAh, and the maximum total reactive energy recorded was 249.716 kVAR, as shown in the figure below;

Figure 18: Total Cumulative Energy Consumption

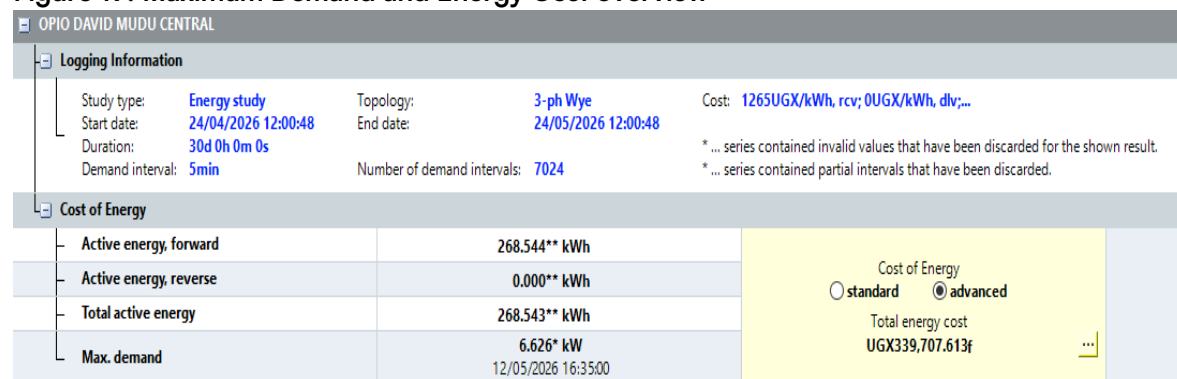


Maximum Demand and Energy Cost

During the one-month (30 days) measurement at Customer #1's Milling machine, we recorded a Total Active Energy consumption of 268.54 kWh and a Maximum Demand of 6.62kW. The facility incurred an electricity energy cost of three hundred and thirty-nine thousand, seven hundred and seven. (339,707.61 UGX) as shown in the figure below;

Customer #1 of Muddu Central operates a milling machine at a cost of 1,265 UGX/kWh, VAT-inclusive.

Figure 19: Maximum Demand and Energy Cost overview



Power Measurements and Analysis for Customer #2's Milling Machine at Ogili Trading Center

The parameters reproduced in this section of the report are limited to those recorded for Customer #2's Milling Machine at Ogili Trading Center and are regarded as relevant to this study for the logging period of 30 days at recording intervals of 1 minute.

Figure 20: Fluke 1736 Installed at the Main Incomer of Customer #2's Milling Machine

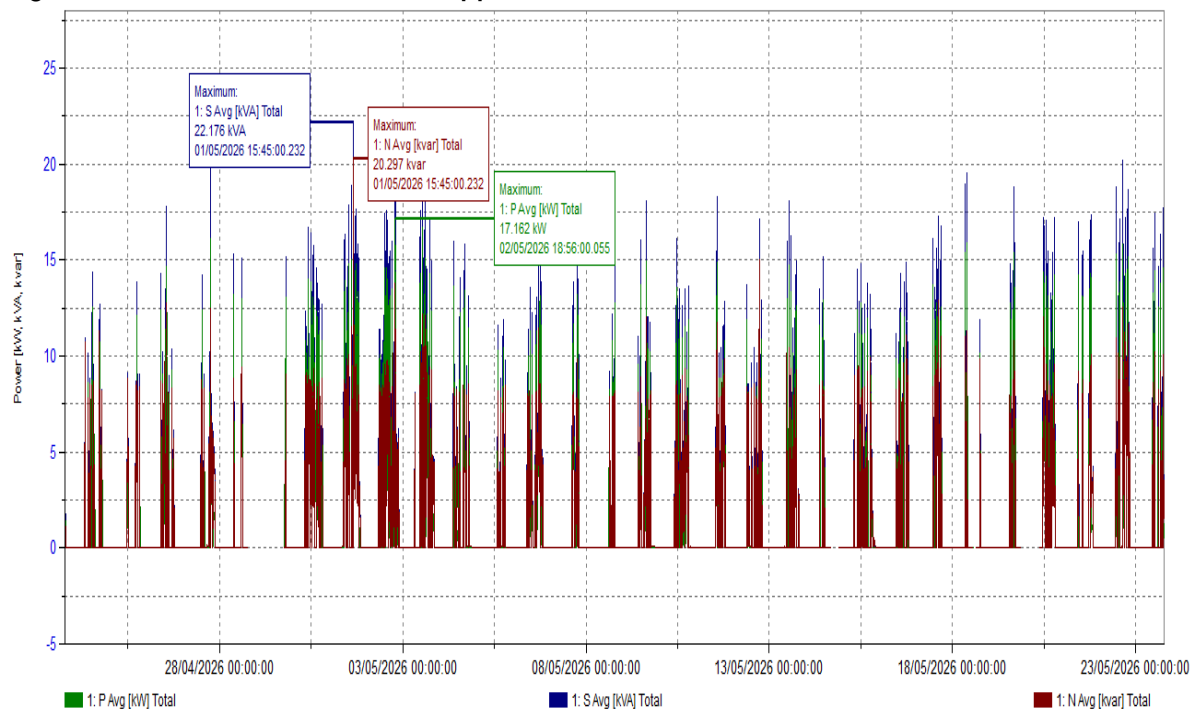


The connection was performed in the measurement topology of the WYE Mode Three-Phase (3ϕ) 4 Wire system.

Power

The average Active Power recorded during the month was 17.21 kW, the average Apparent Power was 22.17 kVA, and the reactive power was 20.29 kVAr.

Figure 21: Maximum Active Power, Apparent Power, and Reactive Power.



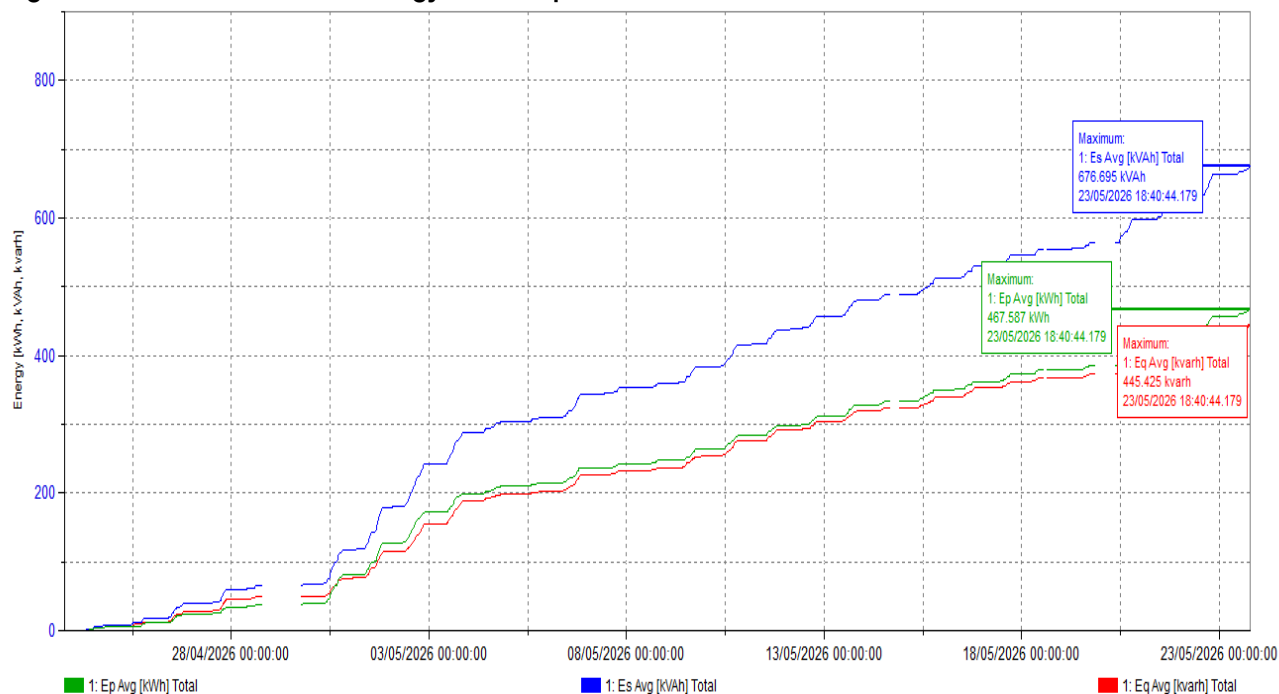
Power Factor

The Maximum and Minimum power factors recorded during the measurement were 0.9 and 0.18, respectively. This low power factor is recorded during low- or no-load conditions. The average power factor recorded was 0.84. Similar to Customer #1, the very large range in power factor values reflects poor loading processes at the mill, which worsen power factor performance, reduce overall energy efficiency, and drastically impact the mini-grid system.

Energy consumption

After 30 days of logging at Customer #2's Milling machine, the maximum total active energy consumed at the facility was 467.587 kWh, the maximum total apparent energy was 676.695 kVAh, and the maximum total reactive energy recorded was 445.425 kVAr, as shown in the figure below;

Figure 22: Total Cumulative Energy Consumption



Maximum Demand and Energy Cost

During the one-month (30 days) measurement at Oburu's Milling machine at Ogili Trading Center, we recorded a Total Active Energy consumption of 467.63 kWh and a Maximum Demand of 12.13 kW. The facility incurred an electricity cost of 587,348 shillings. (587,348.52 UGX) as shown in the figure below.

Figure 23: Maximum Demand and Energy Cost overview for Customer #2's Milling Machines

Project Manager

Energy Study

PQ+ Study

Advanced

Report

RMS Power

Demand

Calendar View

Fundamental Power

V, A, Hz, THD

Unbalance

Energy Loss

Demand overview table

OBURU CHARLES OGILI TC

Logging Information

Study type:

Energy study

Start date:

23/04/2026 18:40:44

Duration:

30d 0h 0m 0s

Demand interval:

5min

Topology:

3-ph Wye

End date:

23/05/2026 18:40:44

Cost:

1256shs/kWh, rcv; 0shs/kWh, dlv;...

* ... series contained invalid values that have been discarded for the shown result.

* ... series contained partial intervals that have been discarded.

Cost of Energy

Active energy, forward

467.634** kWh

Active energy, reverse

0.000** kWh

Total active energy

467.634** kWh

Max. demand

12.135* kW

30/04/2026 10:05:00

Cost of Energy

☐ standard

☒ advanced

Total energy cost

shs587,348.523f

...

Power Measurements and Analysis for Customer #3's Milling Machine of Ogili Trading Center

The parameters reproduced in this section of the report are limited to those recorded by Customer #1's milling machine at Ogili Trading Center and regarded as relevant to this study for the logging period of 30 days at recording intervals of 1 minute.

Figure 24: Fluke 1736 Installed at the Main Incomer of Customer #3's Milling Machine

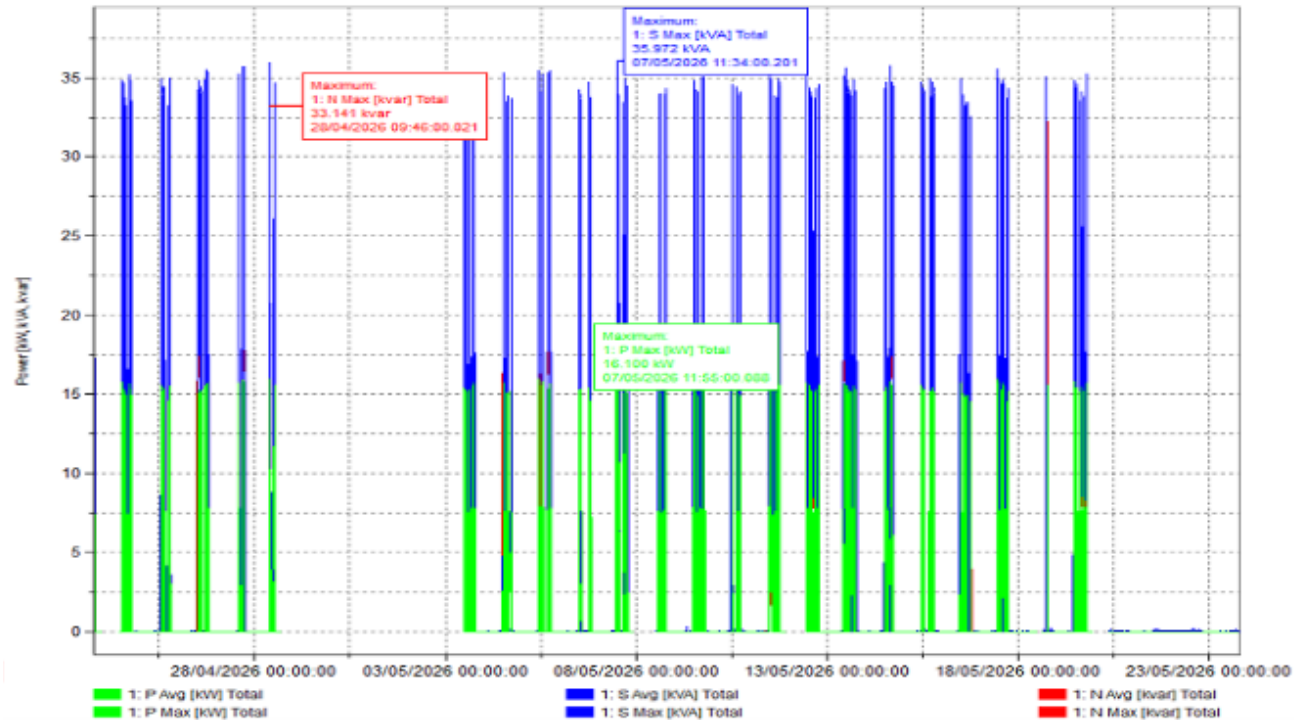


The connection was performed in the measurement topology of the WYE Mode Three-Phase (3ϕ) 4 Wire system.

Power

We recorded 16.100 kW of Active Power, 35.97 kVA of Apparent Power, and 33.14 kVAr of Reactive Power, with an average power factor of 0.86.

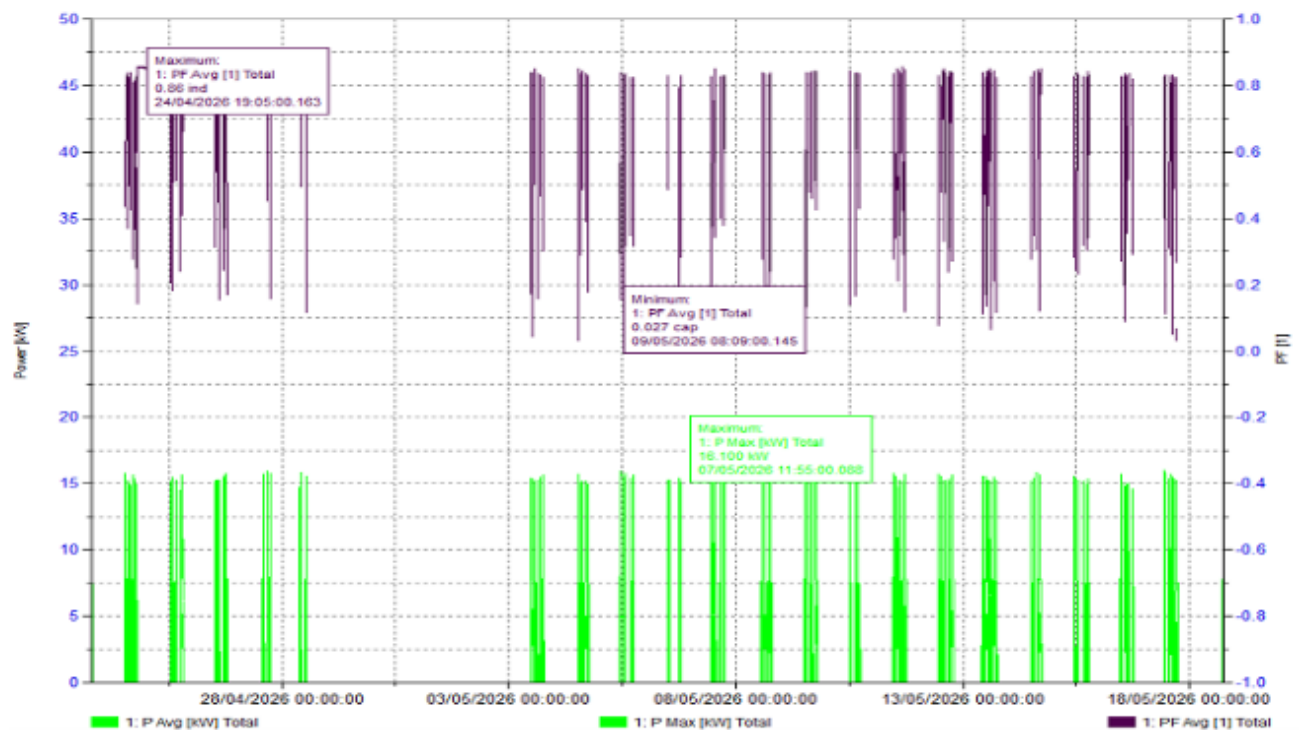
Figure 25: Maximum Active Power, Apparent Power and Reactive Power



Power factor

The Maximum and Minimum power factors recorded during the measurement were 0.89 and 0.027, respectively. The average power factor was 0.86. Similar to Customer #1, the very large range in power factor values reflects poor loading processes at the mill, which worsen power factor performance, reduce overall energy efficiency, and drastically impact the mini-grid system.

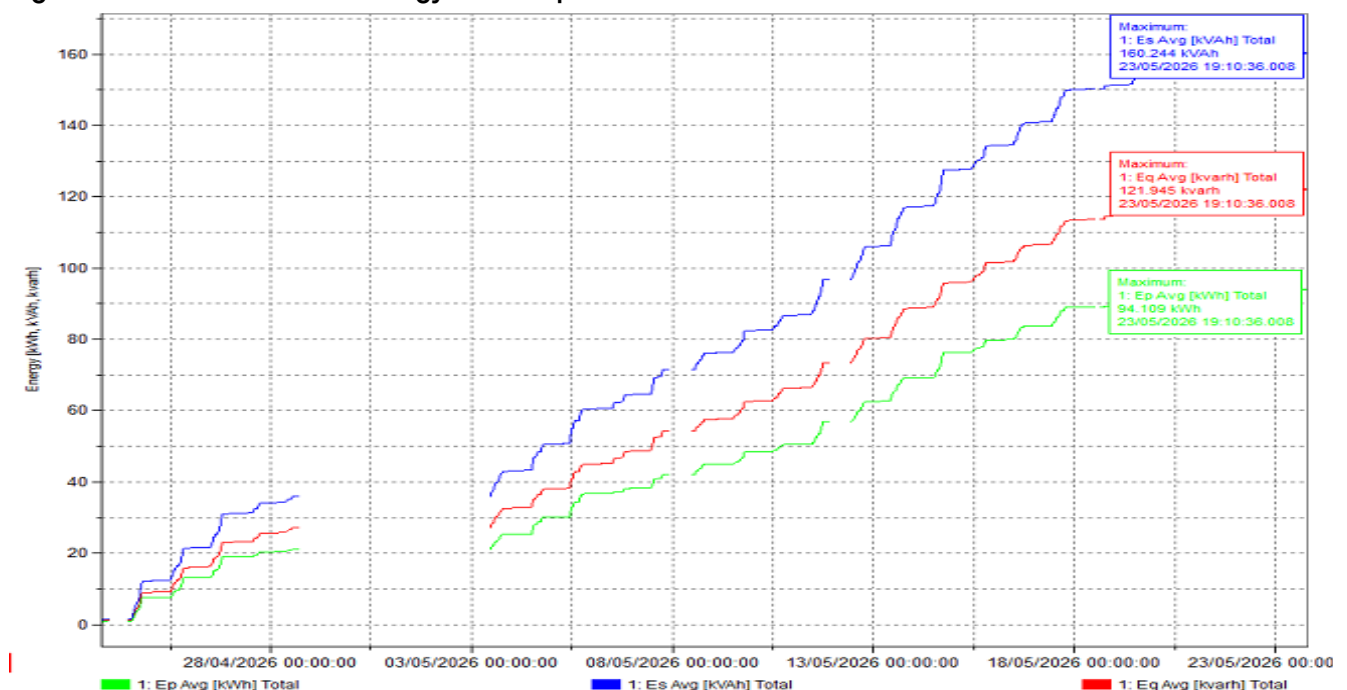
Figure 26: Maximum and Minimum Power Factor Trend



Energy consumption

After 30 days of logging, the maximum total active energy consumed at the facility was 94.10 kWh, the maximum total apparent energy was 160.24 kVAh, and the maximum total reactive energy recorded was 121.94 kVArh, as shown in the figure below;

Figure 27: Total Cumulative Energy Consumption



Maximum Demand and Process Energy Cost

During the one-month (30-day) measurement at Customer #1's Milling machine at Ogili Trading Center, we recorded a Total Active Energy consumption of 94.10 kWh and a Maximum Demand of 5.80 kW. The facility inquired about the electricity cost of 119,047 shillings. (119,047.98 UGX) as shown in the figure below.

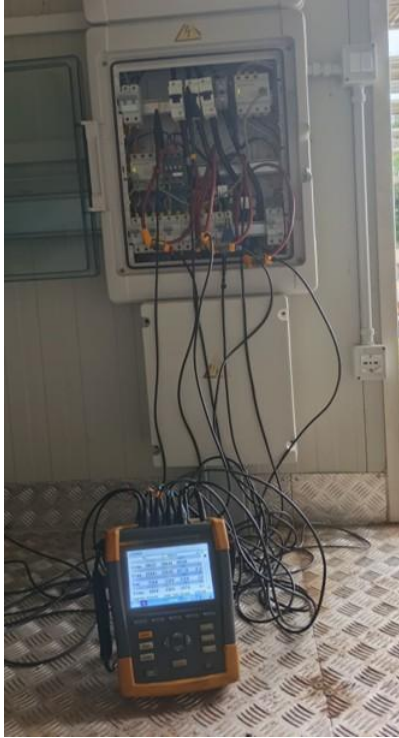
Figure 28: Maximum Demand and Energy Cost overview for Customer #1's Milling Machines

Project Manager		Energy Study		PQ+ Study		Advanced		Report					
RMS Power		Demand		Calendar View		Fundamental Power		V, A, Hz, THD		Unbalance		Energy Loss	
Demand overview table													
TORACH MICHEAL OGILI TC													
Logging Information													
Study type:		Energy study				Topology:		3-ph Wye				Cost: 1265UGX/kWh, rcv; 0UGX/kWh, dlv;...	
Start date:		23/04/2026 19:10:36				End date:		23/05/2026 19:10:36					
Duration:		30d 0h 0m 0s										* ... series contained invalid values that have been discarded for the show	
Demand interval:		5min				Number of demand intervals:		6706				* ... series contained partial intervals that have been discarded.	
Cost of Energy													
Active energy, forward						94.109** kWh		Cost of Energy ☐ standard ☒ advanced Total energy cost UGX119,047.981f ...					
Active energy, reverse						0.000** kWh							
Total active energy						94.109** kWh							
Max. demand						5.908* kW							
						24/04/2026 19:05:00							

Customer #1 is operating a grain milling machine at Ogili Trading Center and is charged 1,265UGX/kWh VAT inclusive

Power Measurements and Analysis for Apyetta Solar Plant

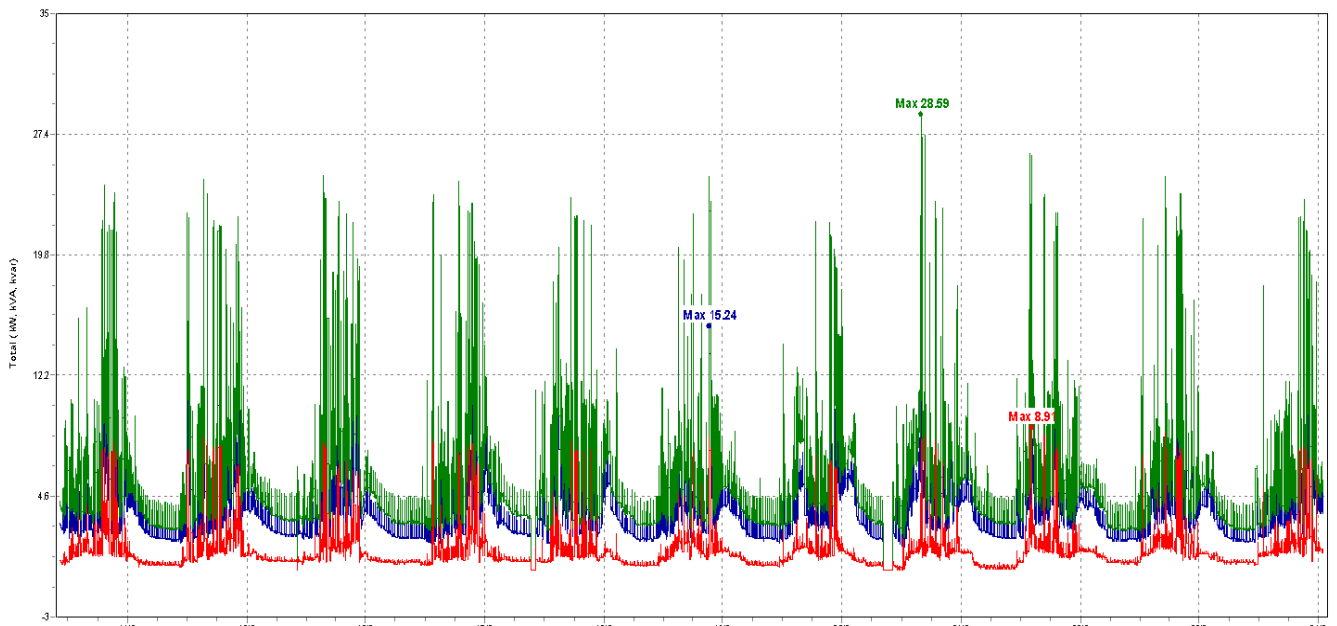
Figure 29: Fluke 1736 Installed at the Main Incomer, Apyetta Solar Plant



Power

The maximum Total Power recorded during the measurement was 15.24 kW for Active Power, 28.59 kVA for Apparent Power, and 8.91 kVar for Reactive Power, as shown in the figure below;

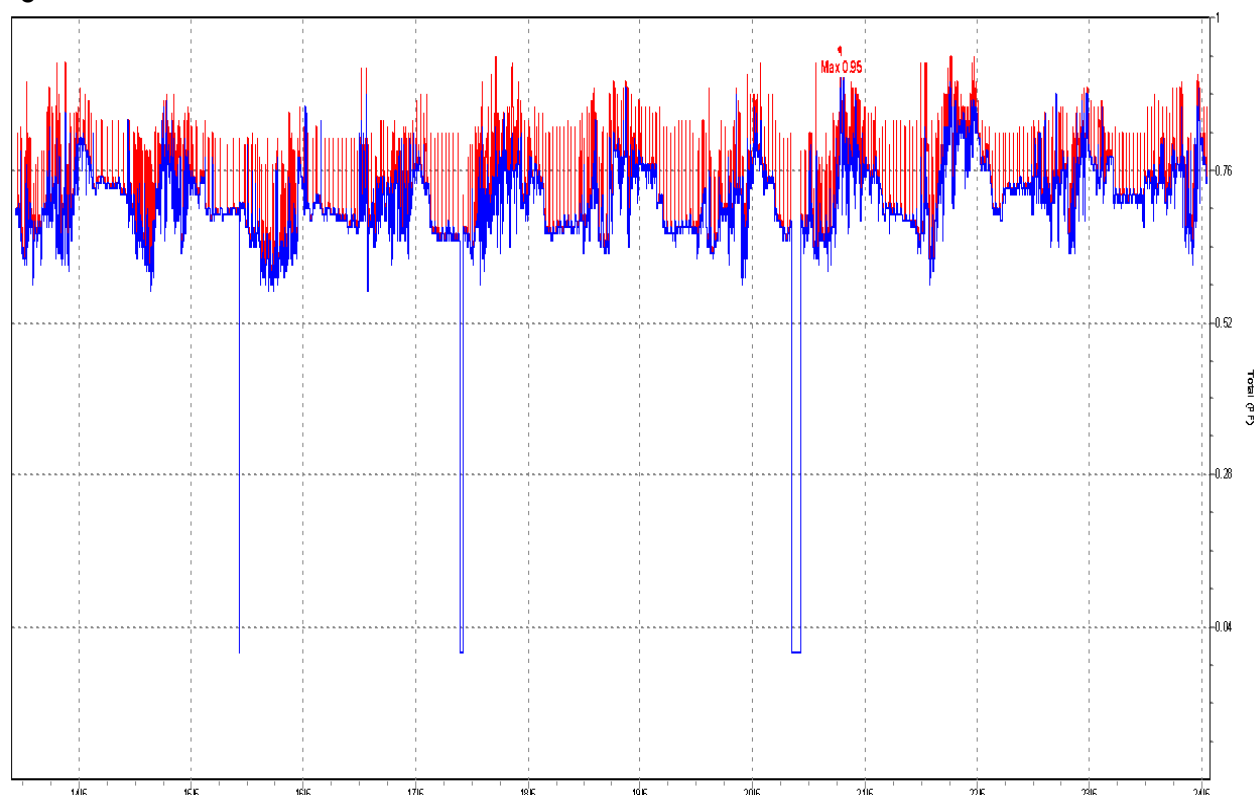
Figure 30: Maximum Active Power, Apparent Power, and Reactive Power.



Power factor

On a typical operating shift, the power factor ranges from 0.1 to 0.95, and the average power factor recorded was 0.70, as shown in the figure below. However, over the entire duration of the load measurement, the 95th percentile of the average power factor was 0.8, and the 5th percentile was 0.6. Similar to Customer #1 and Customer #2, the very large range in power factor and poor power factor reflect poor loading processes at the mill, reducing overall energy efficiency and drastically impacting the mini-grid system's sustainability and reliability.

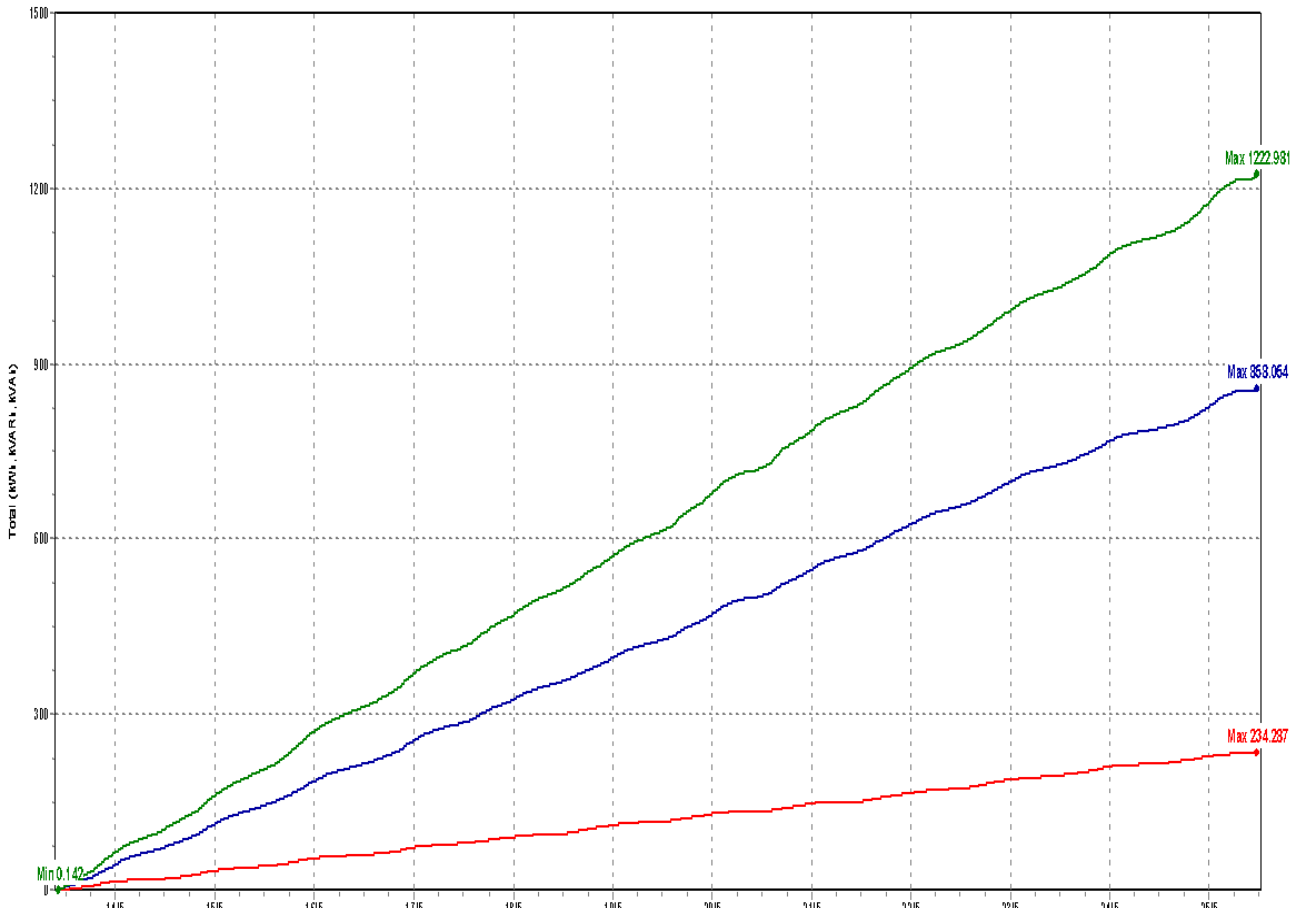
Figure 31: Maximum and Minimum Power Factor Trend.



Energy consumption

After 12 days of logging at the main output of the plant, the Total Cumulative Active Energy discharged from the facility was 858.05 kWh, the maximum total apparent energy was 1,222.98 kVAh, and the maximum total reactive energy recorded was 234.28 kVAr in the figure below;

Figure 32: Total Cumulative Energy Consumption



The figure above shows that the Apyetta Central 40kW peak Mini Grid Solar Plant can generate 5.53kWh per hour.

Production Analysis

The mills in Lamwo do not maintain production records; instead, they estimate average daily production. The table below shows the estimated average daily production for the mills visited.

Table 10: Average production for mills in Lamwo District

#	Item	Average daily production (kg)	Size of maize mill kg/hr	% Plant Utilization Rate
1	Muddu- Customer #1	170	N/A	N/A
2	Ogili- Customer #2	100-130	N/A	N/A
3	Ogili- Customer #3	200	N/A	N/A

Since the mills do not record production, it is difficult to determine their energy-efficiency parameters, such as specific energy consumption (SEC).

Motor Assessment and Performance

Three-phase induction motors powered by solar mini-grids drive the assessed milling operations. The motors serve as key anchor loads for the mini-grids. The specification tag analysis reveals that most motors assessed are IE2 (High Efficiency) class, identified as GUANGLU Y3-160M-4; meanwhile, only one motor has been identified as IE3 (Premium Efficiency) represented by YE3-160L-4 from Hengshui Electric Motor Co. Ltd. The Power ratings of the assessed IE2 and IE3 motors are 11kW (15 HP) and 15 kW, respectively. The IE3-classified motor has a higher power rating, demonstrating differences in both efficiency and installed capacity.

Figure 33: Milling Motor Specifications

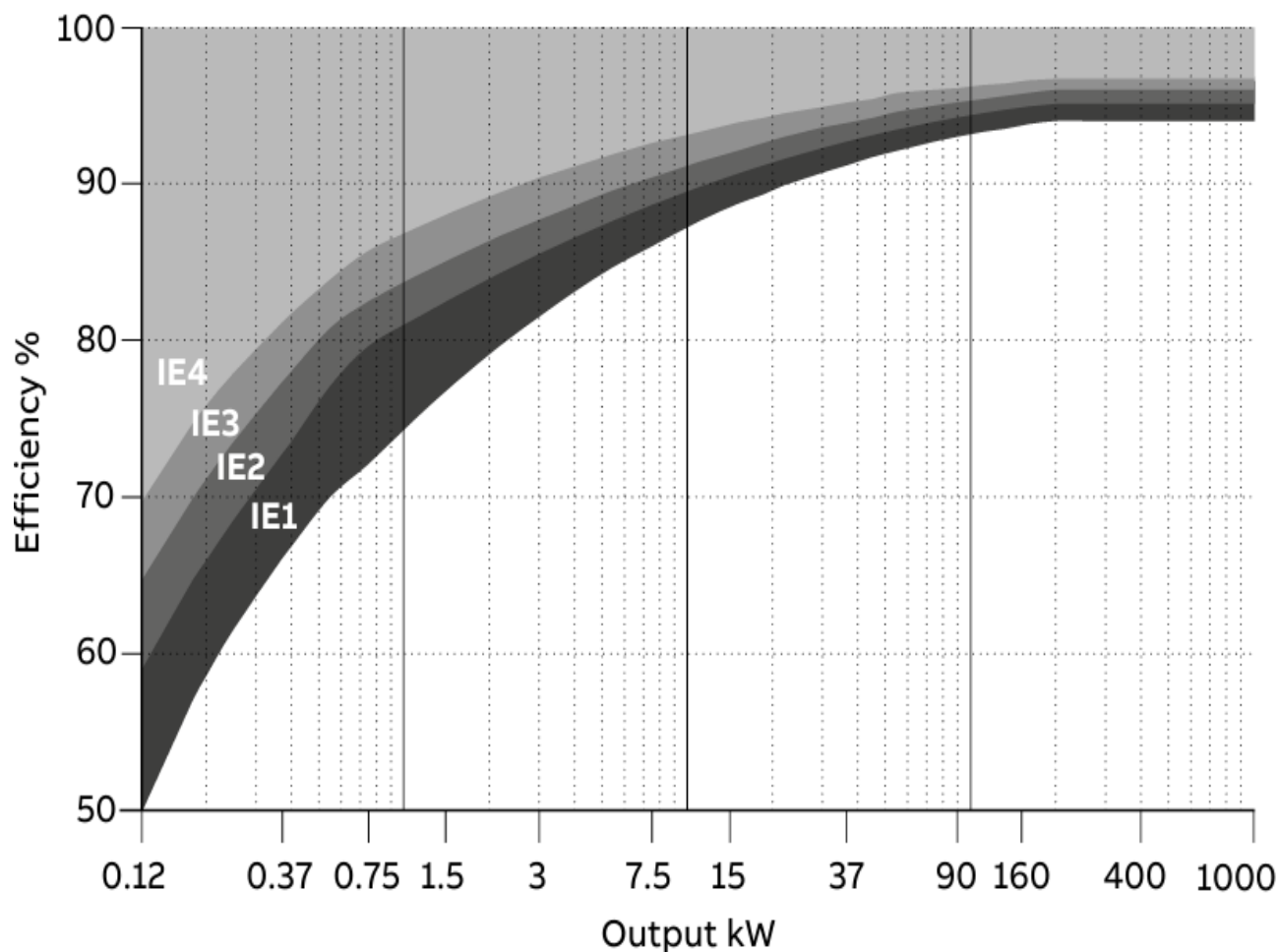
THREE PHASE MOTOR									
IEC 60034-1									
ISO9001									
Type	Y3-160M-4		Nr. 22100080158		103 kg		Δ U ₁ U ₂ V ₁ V ₂		
Isol. F	IP 55	S1	0.84 COS ϕ	75 dB(A)	IEC 60038		Δ U ₁ V ₁ W ₁		
V	HP	kW	A	Hz	RPM	EFF	Y U ₁ U ₂ V ₁ V ₂		
Δ/Y 380/660	15	11	22.5/13.0	50	1460	88.4%	Δ U ₁ V ₁ W ₁		
Δ/Y 460/795	18	13.2	22.5/13.0	60	1752	88.4%	Δ U ₁ V ₁ W ₁		
GUANGLU ELECTRICAL CO., LTD									
TEM 400C IM B3									
MADE IN CHINA									

三相异步电动机									
型号	YE3-160L-4		功率		15 kW				
380 V	28.8 A	效率		IE3-92.1%					
功率因数	0.86	50 Hz	1460 r/min	编号	X061				
绝缘等级	IP 55	绝缘等级	F	工作制	S1				
GB/T 28575-2020				22 kg	21年8月				
衡水电机股份有限公司									
衡水经济开发区新區 電話: 0319-21095									

Both the IE2 and IE3 motors assessed operate at the same voltage of 380 V, frequency of 50 Hz, and rated speed of 1460 rpm. Additionally, the motors are rated for Class F insulation, equipped with IP55 protection, and intended for continuous duty (S1), positioning them as the best motors for a dusty milling environment. However, the two classes of motors differ: IE2 has an efficiency of 88.4% and a power factor of 0.84, while IE3 has an efficiency of 92.1% and a power factor of

0.86. The power output losses for IE3 are lower compared to IE2 because of the higher efficiency⁵ as demonstrated in the figure below.

Figure 34: International Efficiency (IE) classes for 4-pole motors at 50 Hz (Source: ABB Ltd)



The assessment also identified that all the motors possess soft starters, resulting in improved start-up operation by reducing current inrush and limiting electrical and mechanical stress⁶. The stability of voltage and operation of the inverter in a solar mini-grid can be greatly affected by sudden spikes in load; the controlled starter prevents this

sudden load surge⁷. Despite soft starters improving start-up performance of a motor, they are not energy-saving devices; the energy performance of motors is determined by efficiency class, load condition, and rated capacity⁸.

⁵ [9AKK107319 EN 05-2018_20848 ABB Technical note IEC 60034_30_1.pdf](#)

⁶ [How Soft Starters reduce starting current \[2025\] - Emotron](#)

⁷ [Inrush Current Mitigation for Grid-Forming Inverters.pdf](#)

⁸ [How Soft Starters reduce starting current \[2025\] - Emotron](#)

Common brands for induction motors in Uganda include Siemens, ABB, WEG, and Dongchun Motor⁹. The motors are generally expensive, and most are ordered from manufacturers and wholesalers.

Operations and Maintenance

None of the assessed milling sites have a well-structured, documented maintenance schedule and records. Operations and maintenance activities are entirely corrective, with maintenance undertaken only when technical issues occur. Although both the IE2 and IE3 housings are IP55-rated, regular checks of bearing conditions, terminal connections, and cooling pathways are necessary; however, the assessment identified that these routine inspections are limited. Milling operations are dusty in nature; as such, irregular cleaning of the motor surfaces can prevent heat dissipation, resulting in an increase in operating temperature and electrical losses¹⁰.

The assessment also found that the milling operators inconsistently lubricate the motors and rely entirely on their experience rather than following the manufacturer's recommendations. Poor greasing of motors can accelerate friction losses and increase bearing wear, resulting in lower motor efficiency and reduced lifespan¹¹. Furthermore, the history of operating hours, maintenance, and energy consumption of the motors has not been documented by the operators.

Energy Efficiency Opportunities

1. Awareness and capacity building:

Finally, strengthening institutional and operational capacity through training on energy-efficient motor operation, preventive maintenance, energy measurements, and basic energy monitoring would support sustained efficiency gains and enhance the mini-grid business case through reliability and increased margin gains. Establishing simple performance-tracking practices and integrating energy-efficiency considerations into routine operations would enhance both milling productivity and the long-term sustainability of mini-grid systems.

The energy savings from awareness and capacity building cannot be quantified independently, but they apply to all energy-efficiency opportunities in the grain milling facilities. Awareness is the most important lever for accelerating the adoption of not only energy conservation measures but also recommended energy-efficient technologies. This should be prioritized.

2. Replacement of IE2 Motors with IE3

Motors: Despite existing challenges, the study identified several opportunities to further enhance energy efficiency and strengthen mini-grid sustainability. A key

⁹ <https://iecmotors.com/top-induction-motor-suppliers-uganda/>

¹⁰ [Recent Developments in Cooling Systems and Cooling Management for Electric Motors.pdf](#)

¹¹ [Inadequate lubrication | Power-MI](#)

opportunity lies in replacing IE2 motors with IE3 or IE4 motors, particularly during equipment upgrades or end-of-life replacement cycles. Even with soft starters already in place, upgrading to higher-efficiency motors could reduce energy consumption, lower thermal losses, and improve overall system reliability.

Investment cost: The investment cost for a 15 kW IE3 Induction Motor is 1,850,000 Uganda Shillings (~\$507)^{12,13}. Data on the investment cost of induction motors were not obtained during the fieldwork.

The prices of IE3 induction motors tend to be 5-15% higher than those of IE2 induction motors, which guides the economic analysis of the energy-efficiency opportunity.

Annual Savings:

Considering the replacement of a 11kW IE2 induction motor with an IE3 induction motor with 4 pole pairs and a load factor of 70%, which is typical for pumps, fans, and conveyors.

IE2 Efficiency: 88.4%

IE3 Efficiency: ~92.6%

Operating hours: 2,496 hours (8 hours per day, 6 days a week, for 52 weeks in a year)

$$E = \frac{P \times LP \times h}{\eta}$$

P=11 kW, LF=70%, h=2,496 hours

For IE2 Motor, $E = \frac{11 \times 0.7 \times 2496}{0.884} = 21,741 \text{ kWh}$

For IE3 Motor, $E = \frac{11 \times 0.7 \times 2496}{0.929} = 20,755 \text{ kWh}$

Annual energy savings
= 21,741 – 20,755
= 986kWh

The electricity tariff for mini-grid sites in Lamwo District, Northern Uganda, is Ushs 1,072 per kWh (USD 0.29/kWh).

Annual energy savings in Uganda shillings
= 986kWh × 1,072/–
= 1,056,992/– (~\$285)¹⁴

Simple Payback Period (SPP)

Estimated investment cost:

1,850,000 Uganda Shillings (~\$292)

Annual Savings: 1,056,992 Uganda Shillings (~\$285)

Simple Payback Period
= $\frac{\text{Investment cost}}{\text{Annual savings}}$
= $\frac{1,850,000}{1,056,992}$
= 2.9 years

Net present value (NPV):

¹² <https://jiji.ug/central-division/power-equipments/15hp-11kw-three-phase-electric-1480rpm-normal-speed-motor-raEfa1sgKOyiseBQVQTaSnkZ.html>

¹³ 1\$ = UGX 3711

$$NPV = \frac{A[(1+i)^n - 1]}{[i(1+i)^n]} - \text{Initial Investment}$$

Time, t: 15 years

Discount rate, r: 12% (Bank of Uganda rate)

A: Annual savings

$$NPV = \frac{1,056,992 [(1 + 0.12)^{15} - 1]}{[0.12(1 + 0.12)^{15}]} - 1,850,000 = \frac{5,349,084}{-} (\sim \$1,441)$$

Since the NPV is greater than zero, it is a viable investment.

Internal Rate of Return (IRR)

IRR is the discount rate when NPV is zero.

$$0 = \frac{1,056,992 [(1 + i)^{15} - 1]}{[i(1 + i)^{15}]}$$

Using the trial-and-error method,

When i=50%, NPV=259,156 (~\$70).

When i=60%, NPV=-89,874.66 (~\$24)

60% -89,874.66 (~\$24)

Using interpolation, **IRR=57.4%**

3. Installation of variable speed drives

(VSDs): Additional improvements could be made by complementing existing soft starters with advanced motor control solutions, such as Variable Frequency Drives, where technically and economically feasible. While soft starters address startup-related issues, VFDs would enable speed control during operation, allowing motors to better match milling loads and further reduce energy consumption under partial-load conditions.

A variable frequency drive is a type of motor controller that drives an AC motor by varying the motor's supply frequency and voltage. VFDs reduce electrical energy use and allow operators to precisely adjust motor speed to match the system-required load. VFDs reduce the motor energy consumption by between 20-50%¹⁵.

Figure 35: VFD 220V 15Hp 11kW Vector Control Variable Frequency Drive Inverter motor CNC¹⁶

Interest rate (i)	NPV
50%	259,156 (~\$70)
IRR	0

¹⁵ <https://lv.farnell.com/technical-resources/articles/how-to-save-energy-and-costs-with-a-variable-frequency-drive>

¹⁶ https://www.ebay.com/itm/365971054272?chn=ps&_trkp arms=ispr%3D1&amdata=enc%3A1B50WKRzjSAO4oWjFVC1DsQ2&norover=1&mkevt=1&mkrid=711-153320-877651-5&mkcid=2&itemid=365971054272&targetid=325425753764&device=c&mktype=pla&googleloc=9230700&poi=c&campaignid=20797223261&mkgroupid=156754070580&rlsatarget=pla-325425753764&abclid=&merchantid=5337215147&gad_source=1&gad_campaignid=20797223261&gbraid=0AAAAAD_QDh_2HezAgZYLfcH-uMz2BdtNo&gclid=Cj0KCCQjw54nRBhDCARIsAMcY_SAj5WwfDe7OJCUSreFEszANpFNmGohUcAHAfADKivrKV1T1ADWHK8UaAsTWEALw_wcB

aignid=20797223261&mkgroupid=156754070580&rlsatarget=pla-325425753764&abclid=&merchantid=5337215147&gad_source=1&gad_campaignid=20797223261&gbraid=0AAAAAD_QDh_2HezAgZYLfcH-uMz2BdtNo&gclid=Cj0KCCQjw54nRBhDCARIsAMcY_SAj5WwfDe7OJCUSreFEszANpFNmGohUcAHAfADKivrKV1T1ADWHK8UaAsTWEALw_wcB



The estimated investment cost for the above variable frequency drive is USD \$442, equivalent to 1,640,000 Uganda Shillings.

Annual savings=15% of energy consumption of 11kW IE3 motor

$$\text{Annual savings} = 0.15 \times 20,755\text{Wh} \times 1,072 \text{ /-per kWh} = 3,337,404 \text{ /-}$$

$$\text{Simple Payback Period} = \frac{\text{Investment cost}}{\text{Annual savings}} = \frac{1,640,000}{3,337,404} = 0.49 \text{ years}$$

$$\text{NPV} = \frac{A[(1+i)^n - 1]}{[i(1+i)^n]} - \text{Initial Investment}$$

Time, t: 15 years

Discount rate, r: 12% (Bank of Uganda rate)

A: Annual savings

$$\begin{aligned} \text{NPV} &= \frac{3,337,404 [(1 + 0.12)^{15} - 1]}{[0.12(1 + 0.12)^{15}]} - 1,640,000 \\ &= 21,090,606 (\sim \$5,683) \end{aligned}$$

Since the NPV is greater than zero, it is a viable investment.

Internal Rate of Return (IRR)

IRR is the discount rate at which NPV is zero.

$$0 = \frac{3,337,404 [(1+i)^{15} - 1]}{[i(1+i)^{15}]} - 1,640,000$$

Using the trial-and-error method,

When i=90, NPV= 28,701.88 Uganda Shillings (~\$8)

When i=120%, NPV= -527,532 Uganda Shillings (~\$142)

Interest rate (i)	NPV
200%	28,701.88 (~\$8)
IRR	0
300%	-527,532 (~\$142)

Using interpolation, **IRR=205%.**

4. Power factor correction:

Opportunities also exist to improve power quality, including the installation of capacitor banks to enhance power factor and reduce reactive power demand on the mini grid.

Based on energy measurements, the power factors for #2 Customer #3 Mill, Customer Mill, and Customer #1 Mill were 0.86, 0.84, and 0.86, respectively. It is possible to achieve a power factor of 0.98 and 0.99 by installing power factor correction banks (capacitor banks).

Considering Torach Michael Mill as an example for sizing the capacity bank and conducting the techno-economic analysis of

the energy efficiency measures, the following calculations are conducted.

$$\text{Original power factor (PF}_1\text{)} = 0.86$$

$$\text{Final power factor (PF}_2\text{)} = 0.98$$

$$\text{FMaximum active power recorded} \\ = 12.97 \text{ kW}$$

$$\text{kVAR} = \text{kW} \times [\tan(\arccos(\text{PF}_1)) \\ - \tan(\arccos(\text{PF}_2))]$$

Where;

kVAR is the apparent power

P is the maximum active power

$$\text{kVAR} = 12.97 \times [\tan(\arccos(0.86)) \\ - \tan(\arccos(0.98))]$$

$$\text{kVAR} = 12.97 \times (0.5934 - 0.2031) = 5.06$$

We recommend a 5 kVAR capacitor.

Annual savings

Estimated investment cost: 800,000
Ugandan shillings (~\$216)

The expected energy savings from the deployment of capacitor banks are 5- 15%.

Considering 5% energy savings and 6 hours of operation per day.

$$\text{Energy consumption} = 12.9 \text{ kW} \times 6 \text{ hours} \\ = 77.4 \text{ kWh}$$

$$\text{Daily energy savings} = 0.05 \times 77.4 \text{ kWh} \\ = 3.87 \text{ kWh}$$

Annual operating hours

$$= 6 \text{ hours/day} \times 6 \text{ days/week} \\ \times 52 \text{ weeks/year} \\ = 1,872 \text{ hours}$$

Annual savings

$$= 3.87 \text{ kWh} \times 1072 \\ /- \text{ per kWh} \times 1,872 \text{ hours} \\ = 7,766,254 /-$$

$$\text{Simple Payback Period} = \frac{\text{Investment cost}}{\text{Annual savings}} \\ = \frac{800,000}{7,766,254} = 0.1 \text{ years}$$

Net present value (NPV)

$$\text{NPV} = \frac{A[(1+i)^n - 1]}{[i(1+i)^n]} - \text{Initial Investment}$$

Time, t: 15 years

Discount rate, r: 12% (Bank of Uganda rate)

A: Annual savings

$$\text{NPV} = \frac{7,766,254[(1+0.12)^{15} - 1]}{[0.12(1+0.12)^{15}]} \\ - 800,000 \\ = 52,094,904 / (\sim \$14,038)$$

Since the NPV is greater than zero, it is a viable investment.

Internal Rate of Return

IRR is the discount rate when NPV is zero.

$$0 = \frac{7,766,254 [(1+i)^{15} - 1]}{[i(1+i)^{15}]} - 800,000$$

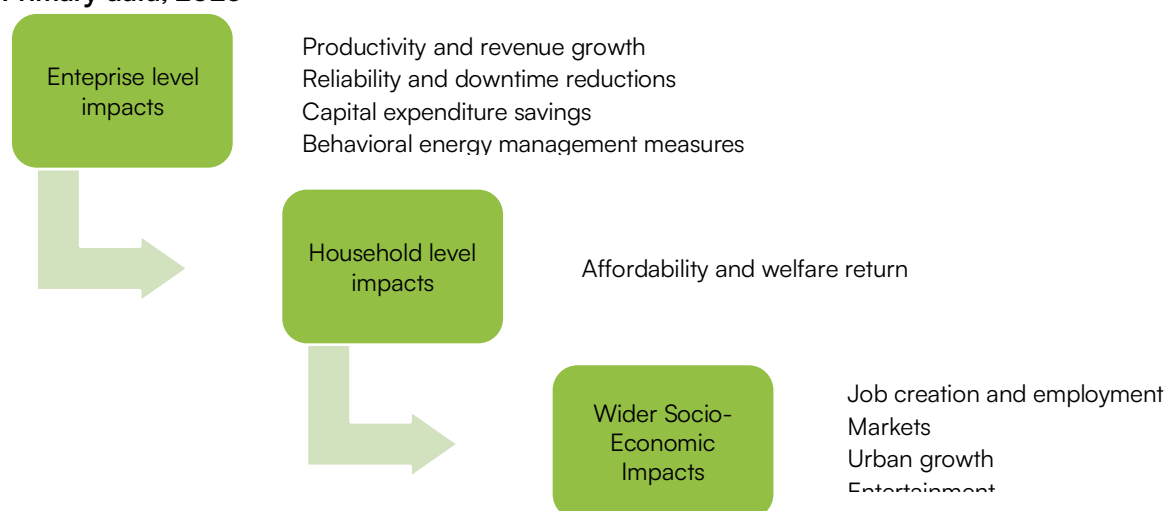
Using the trial-and-error method,

When i=90%, NPV= 7,828,603 Uganda Shillings ((~\$2110))

Since even at an interest rate of 90%, the NPV is positive, the IRR must be > 90%. This is a viable investment.

4. Socio-Economic Impact of Energy Efficiency on Mini-Grid and Milling Performance

Figure 36: Socio-economic impacts of energy efficiency on mini-grid and milling performance
(Source: Primary data, 2026)



5.4.1 Enterprise-Level Impacts

Most milling enterprises in the NOA Lamwo network are micro and small enterprises (MSEs) owned by women and men within the mini-grid service areas, and motor efficiency directly determines the unit milling cost and the hourly throughput capacity. Drawing on the NOA Other Details dataset (2025), the following enterprise-level impact pathways are established.

Table 11: Enterprise-Level Motor Efficiency Impact Pathways (Sources: CLASP East Africa PUE Survey (2023); Exchange rate: 1 USD ≈ UGX 3,711)

* 1\$ = UGX 3711

Impact pathway	Baseline (2025) – Inefficient Motor	Opportunity with efficient motors	Income effect
Milling throughput ((kg/hr)	120–160 kg/hr 	180–220 kg/hr (IE3, full load) 	+38–50% revenue potential 
Energy cost per tonne	UGX 42,000–55,000 (\$11.28 - 14.77)* 	UGX 28,000–35,000 (\$7.52 - 9.40)* 	+UGX 14,000–20,000; Margin gain (\$3.76 - 5.37)* 
Motor downtime / month ((hrs/month)	15–25 hrs 	5–10 hrs 	~UGX 180,000 (\$48.34)/mo recovered; Lost revenue recovery 
Motor replacement cycle	Every 18–24 months 	Every 48–60 months 	UGX 0.8–1.2M (\$214.84–\$322.25) saved / cycle; Capex savings 

Across the three millers interviewed for this baseline, electricity already accounts for most of operating costs, and none of the three keeps

formal production records; output is estimated by feel and by what the day's operations show, which is itself one of the principal evidence

gaps this baseline identifies. The excerpts below show that projected gains are not abstract to the people running the mills; electricity accounts for 70-80% of operating costs for the millers interviewed, making it one of the largest profitability drivers.

“I spend 70% of my monthly income; I spend like shs 20,000 per day on electricity. (KII, M-02, Miller)”

“Electricity consumption is not small; I can assume it accounts for up to 80% of operational costs. (KII, M-03, Miller, Otaa Village)”

Two of the three millers separately described being locked out of power for days at a time after paying," not because the mini-grid had failed technically, but because the payment token had not registered. Some of the reasons that explain this lack of power according to NOA could be attributed to reliability (before 2025 during configuration phase of the Mini grid), metering challenges (the type of meter deployed initially was problematic and had to be changed) and also could be shutdown with payment systems used which cause issuance of tokens challenging. According to NOA these issues have since been resolved and reliability improved to 90%.

“Sometimes I even go like three days without power coming back, yet I paid (KII, M-01, Miller)”

“If you pay on the weekend, it may not come for like three days (KII, M-03, Miller, Otaa Village).”

This “commercial downtime” is distinct from and additive to the 15–25 hours of monthly technical downtime, and is a dimension of motor performance loss that will never show up in an electrical log but will show up immediately in a miller’s daily income.

Millers have also developed their own, entirely self-taught, efficiency practices in the absence of any formal energy management plan. One batches customers rather than starting the motor for each individual order; another redesigned the internal milling parts to cut cycle time and reduce cross-contamination losses between grain types.

“I realized I use a lot of electricity, so I wait to get many customers and start the motor at once, especially in the morning when the customers are very few (KII, M-01, Miller). “

“KII, M-03, Miller from Otaa Village also added that We change the miller inside, because when those parts are over-used it takes time to grind but once we change them, the speed picks up and we use less electricity”.

None of the three millers interviewed has capacitor banks installed, and none budget for energy efficiency as a line item, confirming, from the demand side, the power-quality and reactive-load gap that the metered data already suggests.

At Ogili TC, the largest site with 219 customers and 4 PUE businesses, annual PUE consumption is 3,903 kWh, representing 24.8% of total business-sector consumption (15,737 kWh). This concentration of productive energy demand around milling highlights the

multiplier effect of motor efficiency: a 20% improvement in motor energy-conversion efficiency translates into approximately 780 kWh of freed-up annual generation capacity that can serve additional households or support extended milling hours, directly raising enterprise revenue and reducing queuing losses for farmers.

5.4.2 Household-Level Impacts

At the household level, milling machine performance affects welfare through affordability and the broader welfare dividend of reliable power. Households in the Apyetta service area (33 households, 10 businesses) face annual consumption of 2,245 kWh for households and 2,002 kWh for businesses. The higher SAIDI values at Apyetta suggest that energy affordability constraints, rather than a supply shortage, are limiting consumption. A village representative described what that affordability unlocks once households do connect.

“People now earn some money to feed themselves and buy what they want and pay school fees for their children. This has also helped them get money to take care of themselves when they are sick - they can buy the medicine ... our nurses are now very happy [because vaccines and medicines can be refrigerated] (KII, VR-01, NOA Village Representative, Apyetta Trading Center). “

Energy-efficiency improvements that reduce the per-unit cost of milling services and enhance reliability would directly lower the effective energy-service tariff households face, expanding access to exactly this kind of welfare gain among lower-income users.

5.4.3 Wider Socio-Economic Impacts: Jobs, Markets, Urban Growth, and Entertainment

Beyond direct milling economics, reliable and efficient mini-grid energy access creates a cascade of second- and third-order socio-economic effects across the NOA Lamwo service areas, employment generation, agricultural input markets, non-milling enterprise growth, peri-urban economic development, and social and entertainment services. These wider impacts are increasingly documented in the East African mini-grid literature and are directly relevant to understanding the full welfare dividend of energy-efficiency improvements. The KIIs conducted for this study put faces and numbers to most of them.

Job Creation and Employment Generation

Energy access through mini-grids generates employment across multiple tiers. At the direct tier, each operational maize mill creates 1–3 permanent jobs (mill operator, assistant, security) and 4–8 part-time or seasonal positions (grain porters, weighing agents, packaging workers). Across the three instrumented sites alone, an estimated 21–36 direct jobs are attributable to the 7 installed mills; scaled across the wider network, the portfolio supports an estimated 56–90 direct mill-linked jobs.

At the indirect tier, GOGLA’s Uganda Off-Grid Energy Market Assessment (2023) notes that each productive-use anchor load creates an average of 2.4 additional indirect jobs in complementary services such as grain trading, transport, retail, and equipment repair, while the IFC—ESMAP mini-grid jobs multiplier for Sub-Saharan Africa (2022) estimates 3–5 full-

time-equivalent jobs per 10 kW of installed capacity within 24 months of commissioning. For the NOA Lamwo network's 1.04 MW installed capacity, this implies a potential employment base of 312–520 FTE-equivalent positions.

The village representative interviewed at Apyetta Trading Center is, by his own account, one such job. He also described how mill income itself becomes a channel for hiring people who would otherwise have nothing.

“Without this project, I would not be working with NOA Uganda services. So, I am so privileged to have been employed by this company (KII, VR-01, NOA Village Representative, Apyetta Trading Center).

If a person has a mill, they can employ a person who has never had anything ... so they are also benefiting (KII, VR-01, NOA Village Representative, Apyetta Trading Center). “

Market Development for Agricultural Inputs and Outputs

The availability of reliable milling services fundamentally changes the economics of maize production in the Lamwo catchment. When farmers are confident that harvested maize can be milled within the same day and close to home, they are incentivized to expand cultivated acreage, reduce post-harvest losses through timely processing, and invest in productivity-enhancing inputs. The FAO's Uganda agricultural finance study (2023) found that access to reliable post-harvest processing increases farmers' willingness to purchase certified seed by 28–40% compared with areas with unreliable milling.

This input-market deepening is already visible at the very local level: one miller noted that milling consumables such as screens and replacement parts are now sourced from nearby Palabek rather than from Kampala, a small but telling sign of a local supply chain taking shape around the mills themselves.

“We usually buy spare parts from Palabek, and it's near (KII, M-03, Miller, Otaa Village).

“

On the output side, reliable milling enables small-scale maize flour processing for sale into regional markets, a step up from subsistence milling to commercial agro-processing. This market-deepening effect has been documented in comparable contexts in Northern Uganda under the EARN Project (2024), which found that 23% of households in electrified villages with functional mills shifted from subsistence to commercial maize processing within 18 months of reliable energy access.

Diversification and Growth of Non-Milling Enterprises

The results also revealed that electrification of mini-grid service areas catalyzes enterprise diversification beyond milling. Across the three NOA instrumented sites, 104 non-PUE businesses are registered as electricity consumers (Ayyu Alali: 16; Apyetta: 10; Ogili TC: 78), and at Ogili TC, non-milling business consumption constitutes 75.2% of total business-sector kWh, across retail shops, mobile-phone charging stations, small restaurants, tailoring enterprises, and community health and education facilities.

At Apyetta Trading Center, the village representative described this diversification

taking shape in real time: a groundnut paste processing machine, welding workshops that previously required a 30–35 km journey to access, and salons that could not previously offer services such as hot-combing because they required a steady power supply.

“People came into this very Trading Centre to actually do their business using the electricity ... the G-nut paste machine ... people here also have welding machines (workshops), this wasn’t the case before ... it has created jobs to the youth (KII, VR-01, NOA Village Representative, Apyetta Trading Centre)”

Key non-milling enterprise categories enabled or expanded by mini-grid electricity in the Lamwo context include mobile money and airtime retail, now the fastest-growing service sector in rural Northern Uganda; refrigeration-based businesses (cold drinks, dairy, pharmaceutical cold chain), which require the stable voltage and frequency that motor efficiency upgrades help to deliver by reducing reactive power demand; welding and metal fabrication, which depend on stable three-phase supply; and salon and barbershop services, an important income source for young women and men in particular.

Peri-Urban Growth and Market Center Development

Reliable electricity access, anchored by productive-use loads such as milling, acts as a spatial organizer of economic activity, attracting households, traders and service providers to cluster around mini-grid service points. This agglomeration dynamic is already observable across the NOA Lamwo network: Ogili TC, the largest site with an installed capacity of 80

kWp, hosts 219 customers, compared to 75 and 43 at the smaller 40 kWp sites, reflecting a concentration of economic activity around higher-capacity nodes. Apyetta Trading Center tells the same story in narrative form.

“This place was not the way it is now before the Mini grids. Before, there was no too much development in this centre ... people come and build structures, houses to do their businesses ... so the Trading Centre (TC) has generally developed (KII, VR-01, NOA Village Representative, Apyetta Trading Centre)”

The urbanization multiplier effect of reliable mini-grid energy in post-conflict Northern Uganda has been documented by the International Growth Center’s Uganda urbanization study (2023), which found that trading centers with functional electricity access grew at 3.8 times the population growth rate of unelectrified centers in the Acholi sub-region between 2018 and 2022. For the NOA Lamwo network, this implies that as energy efficiency improvements extend reliable service hours and reduce outage frequency, the service areas will increasingly serve as peri-urban growth poles, attracting return migrants, stimulating land value appreciation, and enabling secondary and tertiary services, including banking agents, pharmacies, and veterinary inputs.

Entertainment, Media, and Social Well-being

Access to electricity for entertainment and information services represents a welfare dimension frequently understated in energy access impact assessments but highly valued by communities themselves. Across the NOA Lamwo service areas, electricity enables

television viewing, radio access for weather and market prices, mobile phone charging, and communal screening of football matches a significant social-bonding activity in communities still rebuilding social cohesion after the LRA conflict. Village representatives consulted under a parallel KII tool confirmed that youth in particular benefit from “entertainment enterprises (discos, radios) and technical vocational work such as welding.”

The GOGLA Impact Report for East Africa (2023) documented that households with reliable electricity access reported a 34% improvement in perceived quality of life, with access to entertainment and information cited as a primary driver. Evening video hall businesses, which charge UGX 500–1,000 per viewer per session, generate meaningful income for operators while serving a social function that is directly contingent on reliable evening electricity supply during the same evening hours that, as Section 4.2 shows, are currently rationed between milling and lighting loads.

Motor efficiency improvements contribute to this dimension indirectly: by reducing reactive power loads and voltage fluctuations caused by inefficient milling motors, grid quality improves for all connected consumers, including evening lighting, television and charging services. The battery utilization data from Ayuu Alali (15% average) and Apyetta (5%) suggests significantly more stored energy is available for evening entertainment and productive loads than is currently being accessed, an untapped welfare dividend that improved system management, rather than further hardware alone, could unlock.

5.4.4 Gender and Social Inclusion Dimensions

The socio-economic impact of motor performance is not gender-neutral, and the KIIs conducted for this study give that observation specific texture rather than leaving it as a general claim. The village representative interviewed at Apyetta Trading Center, when asked directly whether women, youth, and vulnerable groups were benefiting from the mini-grid, was unequivocal.

“Many women are engaged in businesses like salons, of which they are earning. Before electricity, women had salons but had fewer customers since some services that require electricity, like hot-combing, were not possible. The working time was also limited. But now women’s businesses are open up to 10pm ... it makes women also independent and care for themselves. (KII, VR-01, NOA Village Representative, Apyetta Trading Centre). “

Youth benefit through a related but distinct pathway: paid employment, vocational training in trades such as welding, and the option to start their own businesses once those skills are acquired.

“Youths also are doing business, others are employed. Others go to training services; they are learning skills like welding from workshops. The skills they get are now used to make money when they create their own business (KII, VR-01, NOA Village Representative, Apyetta Trading Centre).”

Persons with disabilities and other vulnerable households were described as benefiting indirectly but materially, both through family

members who gain income from electricity-enabled work, and through direct employment at the mills themselves.

“There is a win-win situation ... some come and work on milling machines, so they are also getting jobs (KII, VR-01, NOA Village Representative, Apyetta Trading Centre). “

These findings are consistent with patterns documented elsewhere in comparable Northern Uganda mini-grid corridors: women-owned milling enterprises are disproportionately affected by power quality faults owing to lower capital reserves for motor replacement; households headed by women or

elderly caregivers report the highest time-poverty costs from milling downtime; and improvements in milling reliability and efficiency have a documented positive effect on girls' school attendance, since milling responsibilities frequently substitute for schooling time.

Any energy efficiency intervention program for the NOA Lamwo network must therefore incorporate gender-disaggregated data collection, ensure women millers are primary beneficiaries of subsidized motor upgrade schemes, and track time-use and nutrition indicators as core welfare metrics alongside energy and financial variables.

5. Challenges and the critical leverage point

The prevalence of IE2 motors, compared with IE3s, mainly due to a lack of awareness of the impact of selecting lower-efficiency motors, poses a major challenge for both maize milling operators and mini-grids. IE2 is prone to energy-efficiency losses during extended or partial-load operation. While the 15 kW IE3 motor demonstrates superior efficiency, its limited deployment restricts system-wide energy savings. The efficiency gap between 88.4% (IE2) and 92.1% (IE3) becomes significant over long operating hours, increasing electricity demand on mini-grids and raising operating costs for millers.

The energy efficiency of motors increases with increasing motor capacity. The difference in energy efficiency among motor classes (i.e., IE1, IE2, and IE3) narrows as motor capacity increases. At small motor sizes, the difference in motor energy efficiency is large.

Another challenge is the mismatch between motor capacity and actual milling demand, as seen in the power factor performance. A performance mismatch occurs when the power delivered, rotational speed, or torque does not align with the power required by productive-use operations¹⁷. This happens when the motor is oversized (wasting energy), undersized (causing stall or thermal

overload), or operating at the wrong RPM for the application. In some cases, motors may operate below their rated load, especially during periods of low throughput, which further reduces efficiency, particularly for IE2 motors. Limited understanding of motor nameplate data among operators means that efficiency, power factor, and rated current values are not actively used to guide operational decisions.

There are also financial issues that hinder the rapid adoption of higher-efficiency motors. The milling operations have low throughput, with some estimating that they milled a total of 200kg of grain per day, generating little revenue to replace the low-efficiency motors with high-efficiency ones and greatly impacting power factors, energy efficiency, and sustainability, as already witnessed. The upfront cost of IE3 discourages its widespread adoption, although it offers lower lifecycle energy costs than IE2 which explains the lack of initial adoption of IE3 motors at deployment. There are no financial or incentive mechanisms put in place to rapidly drive the adoption of highly efficient motors in milling operations.

During the training on operations and maintenance for the NOA team at their head offices in Kampala (see images below), NOA

¹⁷ <https://www.3g-electric.com.sg/resources/pumps-compressors-motor-mismatch-troubleshooting-southeast-asia>

and EEAU team critically examined, the barriers and discovered that the root cause of these challenges is not economics; it is awareness, technical skills, and access to financing, which are the critical leverage points to accelerate the adoption of energy efficiency and conservation measures at both the milling sites and mini-grid sites. It is fascinating that all the milling customers lacked even basic practices such as regular dusting, lubrication (see image below), and load-appropriate maize aggregation since NOA, focused on accelerating connections and PUE uptake, had no bandwidth to build efficiency habits into the customer base. The result is a shared loss: customers face high bills and repair costs, while NOA absorbs high O&M costs and slower investment recovery, constraining both commercial viability and the socio-economic case for further electrification. With NOA's pipeline covering 93 new mini-grid sites, embedding energy management now — before scale — is critical. To overcome the anticipated high cost of implementing a target energy efficiency and conservation awareness campaign across NOA's Mini-grid network, grant support is critical. With grant support, NOA will be in a position to:

- Increase awareness, adoption, and utilization of energy-efficiency (EE) technologies among mini-grid communities, focused on agriculture, small enterprises, and social institutions.
- Strengthen NOA Uganda's internal capacity to design, implement, and scale sustainable EE interventions — including market facilitation,

partnerships, and customer engagement.

- Enhance MSMEs' capacity within NOA's service areas to access financing and invest in EE, supporting business growth, higher electricity consumption, and sustainability.
- Promote inclusive access to EE opportunities so no group is left behind in income-generating activities.

The proposed activities to enhance awareness include the following:

A. Increasing Awareness, Adoption, and Implementation of EE Technologies

A structured awareness and market-activation approach across NOA's mini-grid sites: IEC materials (brochures, flyers, posters, radio campaigns) on EE benefits for agriculture, MSMEs, and institutions; community sensitization via radio talk shows, stakeholder meetings, and outreach to youth, women, and entrepreneurs; and capacity-building sessions pairing technical EE knowledge (motor cleaning, lubrication, load aggregation, power-factor basics) with business development, disseminating lessons learned to identify champions and scale successful models.

- Increased awareness and adoption of EE technologies among targeted communities
- At least 100 MSMEs, groups, and institutions adopting EE practices
- Increased participation of women and youth in EE activities
- Improved utilization of electricity for income-generating activities

B. Strengthening NOA's Internal Capacity for EE Delivery

Strategic partnerships with EEAU partners to improve availability of efficient equipment and after-sales support; internal staff training in EE promotion, customer engagement, and investment facilitation; and a dedicated EE support team to guide end users on energy management and track EE performance.

- Strengthened partnerships with EE technology and service partners
- Improved internal capacity to deliver EE interventions at scale
- Increased number of customers using EE technologies through structured support
- Enhanced sustainability of EE activities within NOA operations

C. Facilitating Access to Finance and Strengthening the EE Ecosystem

Technical assistance to MSMEs and productive users to build EE awareness, adopt appropriate technologies, and structure investment cases with identified “Champions of Change” — helping financiers better understand demand. In parallel, engagement with local government and sector stakeholders to integrate EE into local development planning and strengthen the broader investment ecosystem.

- Improved access to financing for EE investments
- Strengthened collaboration between public and private sector actors
- Increased adoption of EE technologies among MSMEs and community groups
- Integration of EE into local development and planning frameworks

D. Promoting Inclusive Access for Women and Youth

Targeted assessments to identify suitable EE technologies for women-led and youth enterprises; partnerships with equipment suppliers and financial institutions to enable flexible financing; and support to social institutions (health centers, schools) to adopt EE technologies (refrigeration, lighting, and other energy-dependent services) that improve service delivery.

- Increased participation of women and youth in EE activities
- Improved access to EE productive assets for women- and youth-led enterprises
- Enhanced income generation and business growth among beneficiaries
- Improved service delivery in social institutions through EE adoption

The awareness project targets beneficiaries within NOA Uganda's existing operational mini-grid sites, aiming to reach at least 200 consumers, with 5 entrepreneurs as direct EE target beneficiaries to be focused on as champions of EE benefits. The beneficiaries will be reached as follows:

- Community sensitization through radio campaigns and local outreach
- Capacity building on business development, EE practices, and equipment utilization
- Facilitated access to EE equipment through partnerships and structured financing

Beneficiaries and Reach

The beneficiaries of the targeted campaign project will gain:

- Knowledge and skills in energy management activities

- Increased income from EE-enabled businesses
- Improved business productivity and efficiency
- Economic empowerment of rural communities using EE-adopted activities
- Increased electricity consumption, supporting mini-grid financial sustainability

Expected results and Key Performance Indicators (KPI)

In the Table below, the expected success indicators or KPIs and results are summarized for the proposed targeted awareness project on energy efficiency and conservation interventions

Table 12: Expected Results and Success Indicators of a Targeted Energy Efficiency and Conservation Campaign

#	Indicator	Data Source	Annual Target	Justification
1	Number of EE participants	Baseline surveys, attendance lists, training reports	200	Aligned with existing PUE consumers; each supported beneficiary serves multiple end-users through goods/services, broadening indirect reach.
2	Number of EE partnerships established	MOUs and contract agreements	2	Underpins sustainability of technical and supply support.
3	Number of EE-supported social institutions operational	Customer database, field verification	3	Each participant (i.e., schools, vocational centers, or health centers) covering universal social needs
4	Number of champions created through EE campaign	Incentives deployed, champion profiles, photos/video	5	Champions act as ambassadors, driving adoption and local employment.
5	Increase in electricity consumption from EE users	Metering and consumption data	20%	Combined EE + PUE adoption is expected to sustain higher demand during business operations.

Sustainability of the intervention

To ensure that the project is sustainable, the following three mutually reinforcing mechanisms are vital:

- a. First, EE awareness activities are designed to stimulate productive energy use, raising both electricity consumption and mini-grid revenue — directly improving the financial viability that pilot data shows is currently being eroded by poor power factor, oversized/underloaded motors, and unplanned outages.
- b. Second, EEAU will work with NOA to secure proper equipment use and maintenance through training and

ongoing technical support, including partnerships with technical experts for periodic routine maintenance at consumer cost — extending equipment life and locking in the learned practices.

- c. Third, the project builds a beneficiary-level income incentive: as EE-enabled appliances generate more income, beneficiaries are incentivized toward proper management and reinvestment, following a Plan—Do—Check—Act cycle intended to sustain adoption beyond the grant period.

Implementation Timeline

To ensure success, it is proposed that the targeted energy efficiency and conservation awareness campaign run for 12 months, from 2027 to 2028, as outlined in the table of milestones, targets, and timelines.

Table 13: Timeline and milestones of key deliverables

Task	Description	Target no.	Timeline	Milestone of Achievement
1	Baseline survey activities: mobilization & stakeholder engagement, radio talk show	200	1 month	Approved data-collection tools, baseline survey report, signed attendance & meeting minutes; photos; radio talk-show recordings and station confirmation
2	Identification of technical experts for MOU on routine maintenance at consumer cost and EE appliance partners	2	1 month	Signed MOUs, engagement photos
3	Detailed capacity-building on EE: mobilization, sensitization, sessions, logistics, adverts	200	6 months	Signed attendance; Training reports, consultant contracts; photos; radio recordings,

Task	Description	Target no.	Timeline	Milestone of Achievement
				small-business start-up training records
5	EE promotion (media) and printing of dissemination materials — Banners, fliers	1000	1 month	Radio announcement recordings; printed materials
6	Consultancy fee	1	2 months	Consultant contracts;
8	Appliance usage monitoring (Field team)	10	Continuous	Field reports, Vending system reports; Metabase / inventory records
9	Periodic community and consumer engagement	2	Continuous	Bi-annual field visit schedules; attendance lists; community engagement reports
10	Consumer monitoring and reporting (incl. transport)	4	2 months	Quarterly monitoring schedules; field reports; attendance; updated deployment/beneficiary tracking; progress reports

Financial proposal for the targeted intervention

To ensure successful completion of the targeted awareness campaign, the following is an indicative budget including contributions from NOA partners.

Table 14: Indicative budget summary for Targeted Energy Efficiency and awareness project

#	Summary of Project implementation activities	Total Budget (USD)	Grant Budget (USD)	Contribution (USD)
A	Baseline activities	1,774	1,774	-
B	Remuneration costs & safety	27,688	25,941	1,747
C	Awareness activities	22,473	21,667	806
D	Capacity Building Sessions and handholding	56,452	48,360	8,091
E	Vendor mobilization & sample appliances	6,586	5,981	605
F	MEL and contingency	13,093	12,571	522
TOTAL		128,066	116,294	11,772

Figure 37: Highly unmaintained milling site typical of the sites visited



Figure 38: Training on Operations and Maintenance for NOA Team at Offices in Kampala



6. Conclusion and Recommendation

NOA Uganda's mini-grids are not being undermined by a shortage of generation capacity or connections, but by the absence of routine, low-cost energy-management behavior at the point of consumption. Power factors as low as 0.45, motors run persistently below 25% of rated load, and outage logs of up to 18 hours at a single site all trace back to the same root cause: milling customers, and the mini-grid operator supporting them, have never been equipped with the awareness and basic skills to use electricity efficiently. None of the technical fixes identified power factor correction, right-sized or variable-speed motors, premium-efficiency replacements can be adopted by a customer who does not yet know they have a problem, what it is costing them, or that a solution exists.

This is precisely why awareness is the activity that merits grant financing now, ahead of and as a precondition for any equipment or financing intervention:

- **It closes a genuine knowledge gap, not a technology gap.** Pilot customers were found repairing or replacing burnt-out motors without ever learning that dust build-up, missed lubrication, and poor load aggregation were the cause of a knowledge gap that costs nothing to close but was never addressed.
- **It is the lowest-cost, highest-leverage entry point.** The cost-benefit analysis shows some of the strongest returns available anywhere in the mini-grid value chain (power factor correction

alone pays back in roughly a month, at over 90% IRR), but that return is inaccessible until customers and NOA staff know it exists and how to act on it. Awareness is the low-cost unlock for a high-return opportunity.

- **It is a one-time investment with a multiplying, pipeline-wide return.** With 93 new mini-grid sites in NOA's pipeline, every efficiency habit and monitoring practice instilled now becomes standard operating procedure at scale, rather than a costly retrofit later. Funding awareness today is materially cheaper than correcting embedded inefficiency across dozens of future sites.
- **Demand for efficiency already exists and is currently going unmet.** The pilot already shows stimulated interest among consumers eager to invest once they understand the benefit, confirming that awareness activity converts directly into demand, and that the constraint today is information, not appetite.
- **EEAU and NOA are a proven, ready-to-scale delivery pair.** EEAU and NOA have already piloted and validated this approach at three sites, with the data, IEC methodology, and delivery relationships in place to scale. immediately reduces implementation risk for the funder relative to funding a new, untested approach.

We therefore recommend that the funder prioritize financing for awareness and capacity

building. These activities are most directly responsible for converting NOA's existing mini-grid and PUE investments into sustainable, efficiently used assets, protecting the funder's and NOA's prior investment in electrification, improving mini-grid revenue and reliability, and building the customer-level foundation that

Low Cost:

Mini-Grid Recommendations

- **Awareness and capacity building:** The level of awareness and capacity building on energy efficiency in mini-grid sites and productive use enterprises is still low. We recommend additional training to improve stakeholders' awareness and capacity for energy efficiency, especially regarding energy conservation initiatives and practices that enhance mill efficiency. This has a high likelihood of acceptance, as the team will disseminate findings to the NOA management and technical teams.

Milling Site Recommendations

- **Record keeping:** The grain millers that were visited were not keeping track of energy and production records. We recommend that the millers employ competent staff who can maintain proper records. Record keeping helps companies understand their performance daily, enabling them to improve energy efficiency by implementing initiatives with clear before-and-after evidence. The NOA management team indicates this is a top-priority recommendation for adoption, as it will improve the generation operations of the mini-grids, not only at the milling sites.

later financing and equipment-upgrade support will depend on. Awareness is not a preliminary step to the real intervention on the evidence gathered; it is the intervention with the most immediate, lowest-risk, and widest-reaching impact available to fund.

Mini-Grid Recommendations

- **Implementation of the energy management system:** An energy management system (EnMS) is a framework for energy consumers, including industrial, commercial, and public sector organizations, to manage their energy use. It helps companies identify opportunities to adopt and improve energy-saving measures through energy conservation and efficient technology deployment, including those that do not necessarily require high capital investment. This involves developing and implementing an energy policy, setting achievable energy-use targets, and designing action plans to meet them and measure progress. We recommend that mini-grid sites NOA integrate an energy management system (EnMS) as part of their milling operations deployments and ongoing maintenance initiatives. This will enhance the socio-economic benefits of the milling operations in the region.

High Cost

Milling Site Recommendations

- **Power factor correction:** We recommend that capacitor banks be installed in all grain mills in Lamwo District, Northern Uganda. The expected

savings from installing capacitor banks are 10-15%. This will also enhance site reliability by reducing unnecessary high current draw from motors relative to the actual power needed and increasing motor lifespan. Power Factor correction must also be incorporated in the planning for future sites with guidance from NOA's (Mini-Grid Site) Business Development team.

The estimate is 800,000 Ugandan shillings. Annual energy savings of 7,2444.6 kWh and 7,766,254 Ugandan shillings. Simple Payback Period of 0.1 years. Net present value (NPV) of 52,094,904 Ugandan shillings and Internal Rate of Return (IRR) >90%. The project is technically feasible and financially viable.

- **Installation of Variable Frequency Drives (VFDs):** We recommend that the soft starters in the grain mills be replaced with VFDs, which will also enhance motor lifespans and increase site reliability. The expected energy savings from installing VFDs range from 20% to 50%. VFDs must also be incorporated in the planning for future sites with guidance from NOA's (Mini-Grid Site) Business Development and management teams.

The estimated investment cost for a 220V, 15 HP (11 kW), vector-controlled, variable-frequency drive inverter motor CNC is 1,640,000 Ugandan Shillings. Annual energy savings are 3,113.3 kWh and 3,337,404 Ugandan shillings. The simple payback period is 0.49 years. The net present value (NPV) is 21,090,606

Ugandan shillings, and the internal rate of Return (IRR) is 205%. This makes the project technically feasible and financially viable.

- **Replacement of induction motors with more energy-efficient ones:** We recommend that the IE2 induction motors be replaced with IE3 motors to increase energy efficiency, lower energy costs, and enhance the reliability of the sites. The estimated investment cost for a 15kW IE3 induction motor is 1,850,000 Uganda Shillings. Annual energy savings are 986 kWh and 1,056,992 Uganda Shillings. Simple Payback Period of 2.9 years. Net present value (NPV) of 5,349,084 Uganda Shillings and Internal Rate of Return (IRR) of 57.4%. This recommendation is technically feasible and financially viable. The use of energy-efficient motors must also be incorporated into the planning for future sites, with guidance from NOA's (Mini-Grid Site) Business Development.

Milling Site Recommendations

- **Review of System Capacity to Enhance Reliability:** We recommend that the NOA Business Development team and Management review the capacity of the Apyetta Mini-Grid site and Ogili Mini-Grid site to ensure that the battery capacity, , is enhanced to cater for the high reliability issues experienced on these sites. The cost and business case for these recommendations will need to be considered on a case-by-case basis; however, the benefits in terms of enhanced reliability are worthwhile.

