PRODUCTIVE USE OF ENERGY IN AFRICAN MICRO-GRIDS: TECHNICAL AND BUSINESS CONSIDERATIONS

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Photo by Peter Weston, Energy 4 Impact

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Acronyms

AC	alternating current
CAPEX	capital expenditures
DC	direct current
E4I	Energy 4 Impact
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
kW	kilowatt
kWh	kilowatt hour
L	liters
LED	light emitting diode
LCC	life-cycle cost
LCOE	levelized cost of energy
MW	megawatts
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PU	productive use
PUE	productive use of energy
PV	photovoltaics
QAF	Quality Assurance Framework
REopt	Renewable Energy Optimization
Vulcan	Vulcan Impact Investing
W	Watt

Important Notices

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The analysis is based on projections, estimates or assumptions made on a best-effort basis, based upon expectations of current and future conditions at the time they were developed.

This analysis relies on information provided to NREL by Energy for Impact that has not been independently validated by NREL.

The analysis results are not intended to be the sole basis of investment, policy, or regulatory decisions.

REopt. This analysis was conducted using the NREL REoptModel (http://www.nrel.gov/tech_deployment/tools_reopt.html). REopt is a techno-economic decision support model that identifies the cost-optimal set of energy technologies and dispatch strategy to meet site energy requirements at minimum lifecycle cost, based on physical characteristics of the site and assumptions about energy technology costs and electricity and fuel prices.

Executive Summary

Demand for electricity from small industry and businesses, which is defined as the productive use of energy (PUE), is a key success factor for micro-grids. Because of the typically low energy usage of residential customers, without linkage to and support for these energy users, micro-grids are likely to struggle to reach the critical revenue needed for financial viability. Productive users are also important to enhancing the economic and social development impacts of micro-grids and rural electrification programs more broadly.

This report is part of a series of reports being developed by the National Renewable Energy Laboratory (NREL) and Energy 4 Impact (E4I) in support of the Power Africa Beyond the Grid Program and is a companion document to the Quality Assurance Framework for Mini-Grids (Baring-Gould et al. 2016). This report is a resource entrepreneurs and developers can use to understand the technical and business model challenges related to PUE in smaller micro-grids. It focuses on small agricultural processing, and small industrial and commercial loads.

This report examines best practices for promoting PUE and the business models used by developers. It starts with background information and a literature review followed by a discussion of key enterprise considerations for productive use (PU) including: value chain and business case analysis, enterprise development and training, appliance financing, and developers running PU businesses. Unlike many other reports on PUE, this report is based on application specific data, in this case data gathered by E4I working with a range of micro-grid developers and PUs in East Africa. The report is also unique in that it provides actual customer demographics and load profiles from PUs on micro-grids operated by PowerGen Renewable Energy in Tanzania, analyzed for a related Power Africa project (Williams et al. 2018). An example of this load data (Figure ES-1) shows the average load profiles of various PUs over the course of a day, clearly demonstrating that different productive use applications can diversify or compound residential energy use patterns.

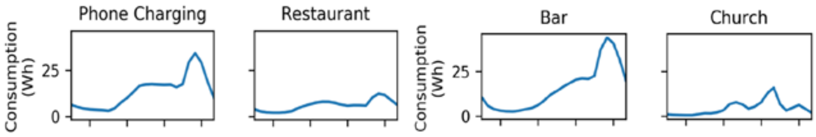

Figure ES-1. Examples of productive use load profiles

Source: Williams et al. 2018

This report considers PUE from both business and technical perspectives, and it considers the interests of both the micro-grid operators and the microenterprises and entrepreneurs they serve. It looks at the service levels required by different PUs and the technical characteristics and challenges of different types of PU equipment. The report also includes examples of business cases for some of the most important PU opportunities, including milling, ice making, carpentry, egg incubation, and water treatment. The example of the business case for egg incubation is shown in Table ES-1.

Table ES-1. Business Case for Egg Incubation

(illustrative information based on E4I data, currency values are in U.S. Dollars)

VARIABLES	VALUES	UNITS
Size of incubator	100	eggs
Power rating of incubator	100	Watts (W)
Capital Cost	122	$
Amount of power consumed per day	2.4	kWh/day
Operational hours	24	hours/day
Operational days per month	21	days
Tariff	0.90	$/kWh
Cost of power	45	$/month
Avg. Expenses per month (including electricity)	83	$/month
Avg. Revenue of sales per month	125	$/month
Net profit	**42**	**$/month**
Profit Margin	**34%**	
Simple payback	**3**	**months**

The report also examines the technical challenges and design considerations for a developer in adding PU loads, such as supporting motor inrush currents and the decision to provide single-phase versus three-phase power to allow different productive use applications. In addition, it analyzes the techno-economics of adding PU from the micro-grid developer's perspective. As an example of the analysis conducted within this report, Figure ES-2 compares the levelized cost of energy and the capital costs of a system that includes a 10 kilowatt (kW) maize mill in Tanzania. The analysis of this system compares a base case system in Tanzania with ones in which the mill is operated under various scenarios: on weekdays between 9:00 AM and 5:00 PM, at 33% loading (2.6 hours per day) or 50% loading (4 hours per day), and seasonal operation (6 months per year). Adding the mill can increase the capital expenditures required for the micro-grid by up to $33,000 (right figure) but can either raise or lower the levelized cost of energy per kilowatt hour (kWh) based on the operating scenario. The cost of energy can be lowered by about 14%, from $1.21 to $1.03, in micro-grids powered by solar photovoltaics and batteries at 50% loading, but can also be raised by 7%, from $1.21 to $1.29, if the maze mill can only be used seasonally at a lower 33% loading.

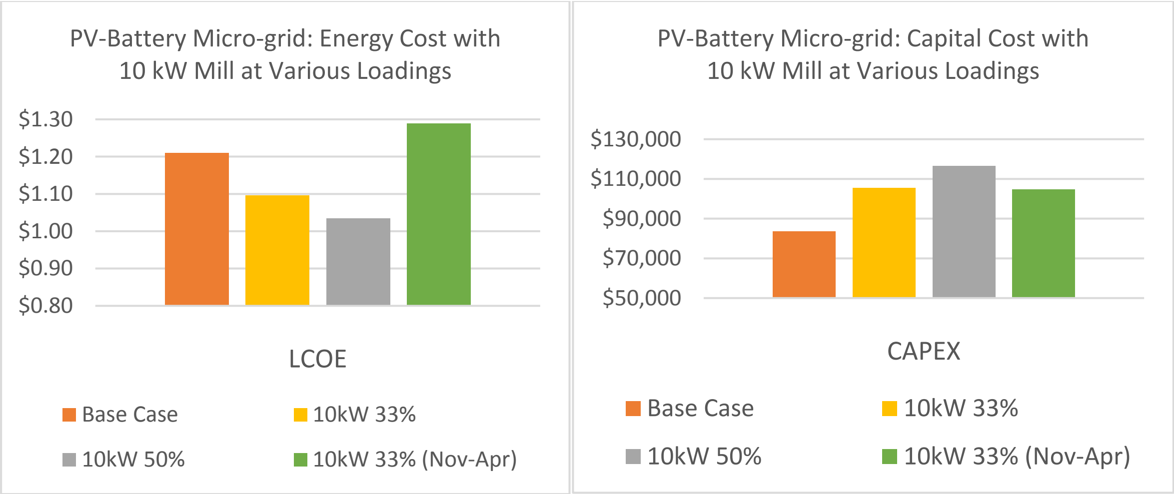

Figure ES-2. Levelized cost of energy (left) and capital expenditures, or CAPEX (right) for photovoltaic-battery system with a maize mill in Tanzania

This report is a resource that entrepreneurs, governments, and non-governmental organizations can use to help design programs to meet their individual goals of PUE in micro-grids and economic development in rural Africa. It can also be used by developers, engineers, and other organizations designing micro-grids to inform their technical and business decisions and to improve system design, reduce risk, and increase success with adding PU loads to both new and existing micro-grids.

Table of Contents

Figures

Tables

1 Introduction

Demand for electricity from small industry and businesses, which is defined as the productive use of energy (PUE), is a key success factor for mini- and micro-grids.[1] Without linkage to and support for these users, micro-grids are likely to struggle to increase local commercial uptake of electricity or reach the critical level of sales necessary to secure their financial viability. Productive users are also an important part of enhancing the economic and social development impacts of micro-grids and rural electrification programs more broadly. Potential impacts of PUE include increased local economic activity, added value to products and services, job creation, and enhanced gender equality.

Many different models have been tried and tested to promote PUE, but there is no "one size fits all" solution. The most successful models usually have four things in common:

- Their approach focuses on the business needs of the productive uses (PUs).
- They foster the development of new PUs around existing value chains to increase productivity or the value of goods sold.
- They include targeted business development services for local entrepreneurs.
- They make available grants or microfinance to stimulate investments in income-generating equipment.

Matching electricity demand with supply is also critical to the success of micro-grids, and many developers aim to shift demand from times of lower renewable resource availability to times of higher availability through demand-side management. It is difficult for micro-grids to achieve this balance because demand can be volatile as a result of the relatively small number of customers, the seasonality of rural economies, and the modest financial means of consumers. Some PU appliances can also present technical challenges for the micro-grid operators if they are not managed properly or systems are not designed appropriately.

1.1 Background

This report is the first of three knowledge articles written by Energy 4 Impact (E4I) and the National Renewable Energy Laboratory (NREL) with support from Power Africa. NREL and the U.S. Department of Energy have developed a Quality Assurance Framework (QAF) for Mini-Grids (Baring-Gould et al. 2016). This framework has the dual goals of (1) defining a range of service levels that ensure safe, quality, and affordable delivery of electricity and (2) providing an accountability framework that can be used to determine whether an agreed-upon service level has been delivered.

This report is a companion document to the QAF. It is a resource for entrepreneurs and developers to understand the technical and business model challenges related to PUE in smaller micro-grids—those with a capacity of 5–100 kilowatts.[2] It focuses on small agro-processing, industrial, and commercial loads rather than large anchor loads, which tend to be absent in most micro-grid locations.

This report looks at best practices for promoting PUE and the different business models used by developers. Unlike many other reports on PUE, this report is based on data gathered by E4I while working on the ground with a range of micro-grid developers and PUs in East Africa. The observations and information in this report come from direct experience by E4I and NREL. Much of the data and information comes from E4I experience supporting PU in eight different village micro-grids in Kenya and Tanzania from November 2016 to April 2018. E4I supported the micro-grids by providing business and technical mentorship services to the PU businesses to increase uptake of

[1] The terms "mini-grid" and "micro-grid" do not have clear or consistent internationally recognized definitions and are used somewhat interchangeably by many industry stakeholders and practitioners. In this report, we use the single term micro-grid for simplicity but do not attempt to distinguish it from the term mini-grid, which could also apply in most instances. See Section 1.2 for how we define micro-grids.

[2] Micro-grids with a capacity of less than 5 kW tend to target private households rather than productive users.

electricity demand. Anything not from the authors comes from other sources and is cited. The report considers PUE from both commercial/business and technical/engineering perspectives, considering the interests of both the micro-grid operators and the microenterprises and entrepreneurs they serve.

This report explains why PUE matters for micro-grid developers and why it can help rural economic development. It also looks at the service levels required by different PUs and the technical characteristics and challenges of different types of PU equipment. The report includes examples of business cases for some of the most important local value chains, including milling, ice making, carpentry, egg incubation, and water treatment.

1.2 Definitions

For the purposes of this report, a micro-grid consists of small-scale electricity generators—such as solar photovoltaics (PV) or engines and possibly energy storage systems—connected to a distribution network that supplies electricity to a small localized group of customers. Such micro-grids are operated independently and are not interconnected with a national grid. Off-grid power systems can range in size from a few kilowatts (kW) up to 10 megawatts (MW). This report focuses on micro-grids with a capacity of 5–100 kW.

PUE may be defined in different ways. Narrowly defined, it refers to activities that generate income, increase productivity, enhance diversity, and create economic value through the consumption of electricity.[3] More broadly defined, it includes all socio-economic uses of electricity that improve quality of life and local resilience (e.g., electricity for education, healthcare, and other welfare services).

The PUs covered in this report are microbusinesses and small businesses based in rural areas. Most of them are active in agriculture or related processing, light manufacturing, or small commercial and retail trading.

[3] The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) defines PUE as "agricultural, commercial and industrial activities involving energy services as a direct input to the production of goods or provision of services" (GIZ and EUEI-PDF 2013).

2 Review of Productive Use Literature

Much has been written about how to scale up micro-grids in sub-Saharan Africa and the role of PUE in that process. Some of the key factors that have been identified for growth include:

- The creation of viable micro-grid business models and the need to include PUs
- Better market linkages with and information on potential micro-grid users, including existing and likely future demand, ability and willingness of users to pay, and local value chains
- Increasing the capacity and skills base of developers, users, and other stakeholders
- Access to finance for both the micro-grid operators and their users.

PUE is an important consideration, but there are a number of related factors that are also important for growth in the sector. For more information on the general challenges and potential solutions for micro-grid scale-up, see Energy 4 Impact and INENSUS (2016) and the eight principles of the Africa Mini-Grid Developers Association.[4]

PUE has an important role to play in micro-grids and rural economic development. The rationale for including PUE in micro-grid business models is twofold. Firstly, the revenues generated by household customers are often small because of low levels of electricity consumption. By fostering PUE, operators can increase the average electricity consumption and revenue for the micro-grid, thus improving the chances of long-term viability. Secondly, PUE can improve rural livelihoods through the opportunities created for increased income, new businesses and jobs, and access to a more diversified pool of products and services. Any potential livelihood improvement may also increase residential demand and the ability to pay for electricity, which improves the overall viability of the micro-grid business model.

Much of the existing literature on PUE focuses on investigating the link between use of electricity and economic activity and the enabling environment for PUE. Some studies suggest that electricity has limited impact on increasing the income of microenterprises and small enterprises. Grimm, Hartwig, and Lay (2011) found that electricity supply had no systematic or uniform influence on the profits of small tailoring businesses in Ouagadougou, Burkina Faso. In fact, they concluded that the supply of electricity could be a financial burden because of the high cost of grid connection and electrical appliances. These financial burdens may be even more pronounced for some marginalized rural economies.

Other studies suggest that there is a positive correlation between electricity supply and the creation of new enterprises and jobs. Dinkelman (2008) concluded that South Africa's post-apartheid rural electrification program led to a 13.5% increase in female employment because the availability of electricity enabled new businesses to produce local goods and services that were previously "imported" at a higher cost. This in turn helped lower local prices, increase local savings, enhance local economic activity and create local jobs.

These studies show that access to electricity can help trigger economic activity under certain conditions, but that access is not always enough and that other barriers, such as the high up-front costs of electrical appliances, may require additional consideration to help stimulate economic activity. Additional research on how micro-grids can enhance or improve PU, which PU applications are most compatible with micro-grids, how to address the relatively high upfront capital to purchase appliances, and how to improve the uptake of these PU applications is necessary, but some work has been done to analyze these connections. These conflicting findings also point to the need to develop a PU strategy, not just implement a potential PU concept. A PU strategy for a community or

[4] "Principles," Africa Mini-Grid Developers Association, http://africamda.org/index.php/principles/.

development model would take a more holistic approach, considering and addressing many of the topics that are introduced in this document.

Vulcan Impact Investing (Vulcan) is one of a few micro-grid developers that has published its own research on the uptake of electricity (Blodgett et al. 2016). According to Vulcan, there are several pre-conditions for a successful PU strategy. Firstly, access to finance at the project and enterprise level is important, including dedicated funding for PU businesses and enhanced mobile payment solutions. Secondly, the policy and regulatory framework needs to create micro-grids with viable business models to serve productive users. Thirdly, it is important to provide capacity building to local communities and enterprises, and to share experience and best practices. Vulcan also found that a minority of the customers of its Kenyan micro-grids[5] consumed most of the electricity. The top 10% of customers (small businesses) generated five times the average revenue per user of the remaining 90% of customers and 40% of total revenue. Most customers consumed fewer than 250 watt-hours/day, yet they remained important as a hedge against the loss of higher use customers. Electricity demand fluctuated widely by month and season, with demand being highest in December and lowest in February.

Another report based on Vulcan data examined the results of energy demand surveys and the implications for correct system sizing; Blodgett et al. (2017) compared forecast demand with actual consumption and found that forecasts were on average more than four times actual consumption, which has led to many micro-grids being oversized. While oversizing a micro-grid system reduces its financial viability, undersizing can also negatively affect a micro-grid's value to PU businesses: if a business cannot depend on the micro-grid for power supply, it employs coping strategies using alternative sources of energy.

It is also important to contextualize PU in the host community to explore the potential for economic development and understand existing and potential demand for electricity in detail (Lecoque and Wiemann 2015; Contejean and Verin 2017). This means micro-grid developers should consider existing energy sources and economic activities when developing solutions and exploring potential new activities. New activities should be embedded in existing market value chains, otherwise substantial support will be needed to build new markets. Furthermore, the community should support new initiatives that are developed and business models that are deployed. Developers can play a role in sharing knowledge, building capacity and providing access to machinery. Also, community services such as churches, schools, clinics, and irrigation should be considered when developing a PU strategy, as they may impact current and future load.

Appliances for PUs are also not well covered in the literature. However, Global LEAP has published a report on the global off-grid appliance market (Global LEAP 2016) that includes information on key market trends in three appliance categories: fans, televisions, and refrigerators. Global LEAP concluded that promoting off-grid appliances beyond lighting and cooking was important for driving social impact. The report also highlighted that awareness and understanding of the off-grid appliance market was limited and that increasing energy efficiency was the key driver for new commercial opportunities.

[5] Vulcan has 10 operating solar mini-grid or micro-grid sites of between 1.5 kW and 6.0 kW.

E4I (Ireri 2018) looked at the market for refrigeration in Uganda and found there was a clear business case for AC-powered energy-efficient refrigerators for retail microbusinesses selling drinks, in both on-grid and off-grid settings. A typical product for a microenterprise is a 100 L–150 L refrigerator costing approximately $250. Refrigerators enable diversification of products sold, provide additional revenue streams to non-retail related businesses, and improve competitiveness. The main challenges for microenterprises are the high energy costs related to the high energy consumption of the refrigerators, power supply interruptions,[6] and the suitability of the products for their business needs (e.g. robustness, design features, and usability). Some businesses managed consumption by switching off refrigerators intermittently. An example entrepreneur operating this type of business is shown in Figure 1.

Figure 1: Example refrigerator use for a microenterprise

Source: E4I

[6] This is more of an issue for the main electricity grid rather than micro-grids.

3 Entrepreneurs: Key Considerations for Business Cases

There is no standardized business model for developing PU around micro-grids. Many different types of PU businesses exist in rural areas—each with their own unique value chain and local characteristics—and the track records of these businesses vary widely. Some micro-grid developers have tried to support existing PU value chains by providing local enterprise support or finance for PU electrical appliances. Some have introduced new value chains and encouraged people or organizations from outside the community to invest in new PUs. Others have invested directly in the PU businesses themselves, generating an alternative income flow to that of the micro-grid. In this section, the report examines these ideas and looks at the key steps in developing a successful PU strategy, namely:

- Value chain and business case analysis
- Enterprise development and training
- Productive use financing
- Developer operated PU businesses.

This section focuses on key challenges for the entrepreneur, Sections 4 and 5 focus on key challenges for the developer, and Section 6 presents entrepreneur case studies.

3.1 Value Chain Analysis and Business Case Assessment

Most PU businesses operating in small village micro-grids fall into one of three categories based on E4I experience:

- Primary industries (e.g. agriculture, fishing, meat and dairy livestock, and timber)[7]
- Light manufacturing (e.g. carpentry, welding, tailoring, and ice making)
- Commercial and retail enterprises (e.g. phone charging businesses, grocers, hair salons, restaurants, video and satellite screening, cafes, popcorn makers, and small freezers).

For many communities, particularly agricultural ones, it is important to start by looking at any existing products, services and activities that may originate in the village and consider how value can be added through the supply of electricity or services derived by electricity supply. Many products produced at the village level have little or no processing or value-adding activities linked to them and, where those activities do exist, they are often minimal and done manually. Community based economic development combined with load expansion can be achieved by exporting higher value products and services outside the village economy. Examples could include agricultural processing or the milling of lumber in place of exporting of raw timber. Similarly, looking at what products or services are imported into the village that could be provided locally can provide ideas for local productive use, such as ice or local services.

For some activities, electricity acts as an *enabler* to make a product or service possible (e.g. ice making). In others, electricity is a *catalyst* that improves the product (e.g. electric milling or woodworking appliances). Electricity can also be a differentiator that does not change the product or service but does change the user experience (e.g. refrigerators to cool drinks).

[7] The most common primary industries are production of cereals and grains (e.g. maize, cassava, sorghum, and rice); oil seed production; small-scale fruit and vegetable farming (especially products where there is high urban demand, such as onions, tomatoes, French beans, and pineapples); small-scale coffee, tea, and cocoa farming; chicken and pig farming; fishing, particularly lake fish such as tilapia and Nile perch.

To develop an effective PUE strategy, it is important to analyze the local value chain for different PU businesses in four main areas (Figure 2):

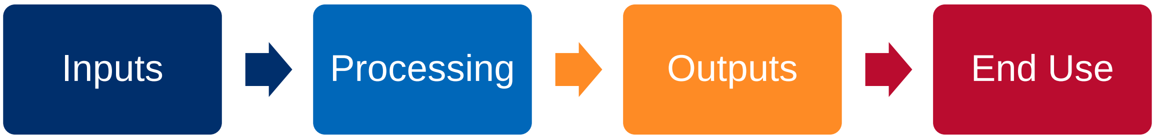

Figure 2. Rural value chain

Inputs or primary production includes intake of raw materials or commodities such as agricultural products, water, or wood. Processing involves value added activities utilizing these inputs such as drying, milling, or water treatment. Outputs are the value add products such as flour, lumber, or clean water and the export of these products or the sale of them in the local community through small enterprises. End use is the consumption or use of these products by the end consumers such as the consumption of food products or the construction of housing. Some examples of operating PU businesses in rural Africa are shown in Figure 3.

Figure 3: Example productive uses including bakery, welding, movie theatre, and cafe

Source: E4I

The value chain for specific crops or products can be quite complex, and it can be helpful for entrepreneurs to understand where they fit in the existing value chain and how their position may change with the addition of PU. An example of the specific value chain related to maize in Kenya (Figure 4) shows the complexity of understanding the actors, markets, inputs, outputs, and other key attributes of a single commodity. It also illustrates how these variables change depending on which part of the chain an enterprise is targeting as farmers and millers occupy very different positions.

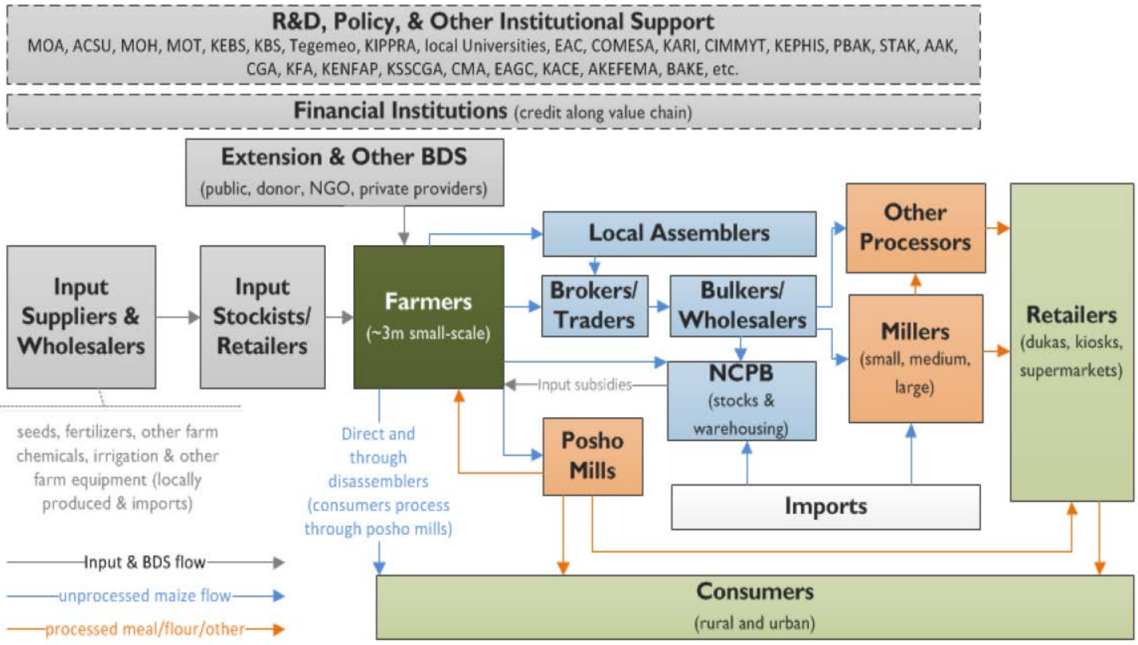

Figure 4. Maize value chain actors and components

Source: USAID 2015, p. 32[8]

PUE interventions must also be rooted in the business interests of the entrepreneurs, including what they need to succeed in their markets and what investments would make financial sense given their expected cashflows. This means looking at every part of the entrepreneurs' businesses, from the amount and quality of their products and the time spent on production and services, to revenues and costs (including electricity costs), supply chain/feedstock strategy, local access to markets, and market prices.

3.2 Enterprise Development and Training

Successful enterprise development cannot be delivered by quick fix solutions—it requires a holistic approach covering all the factors that make for a successful business, which takes time. Mentoring is needed to help build the commercial and technical skills of local entrepreneurs, to train them in using electrical appliances, and to help their businesses navigate the challenges of early development. Mentoring could be provided by governments, non-governmental organizations, or potentially developers themselves if they had the necessary capacity and knowledge. Local PUE champions should be identified and recruited to mentor and inspire others. It requires sustained interaction as rapidly delivered training alone is quickly forgotten. A deeper long-term partnership with the entrepreneur is more likely to deliver long-term results.

A distinction must be made between working to expand services of existing businesses through electrification and the development of new businesses that are enabled by access to electricity. Entrepreneurs with existing businesses are more likely to have a basic knowledge of running a business and the market for their product, even if they are not necessarily familiar with the electrical appliances. Those being trained in new businesses may need to be taught the basic foundations of running a business and to learn about a new product. They will require more comprehensive mentoring over a longer period with a more intense follow-up (GIZ and EUEI-PDF 2013).

Both approaches are valid from a development perspective. Existing businesses might be able to grow more quickly, create more employment, and earn more income in less time. Start-up businesses

[8] See source document for a definition of acronyms utilized in this figure.

have the potential to help additional individuals and improve their lives, but it may take longer to achieve concrete results. For a step-by-step guide to enterprise development, see Appendix A.

3.3 Equipment Financing

Equipment financing is a critical component of enterprise development. This is especially true for PUE, where the capital costs of some equipment and appliances can be high relative to the financials of the enterprise. Entrepreneurs often struggle to get the required financing, and—because of the remote location and off-grid nature of many micro-grids—there are often no formal or even informal financial institutions close by.

Some micro-grid developers have set up their own financing schemes (e.g. concessionary loans or grants) to bridge the gap. They may finance the enterprises directly or through third parties, such as a local financial institution or a supplier of appliances. Although similar in construct, appliance financing can also be used to expand residential energy consumption, but it may not have the same impact as PU development, although the specific equipment may be identical. For example, in Tanzania, Jumeme, Rafiki Power, and PowerGen act as financial intermediaries themselves and provide equipment loans to customers from their own balance sheet. Mwenga Power piloted a partnership with a local microfinance institution—the Mama Bahati Foundation—that provided loans to some of the Mwenga customers for asset finance in Tanzania. The main advantage of the first approach is that the developer has direct control over the financing strategy and the choice of equipment (which should be appropriate for both the entrepreneur and the micro-grid). However, it can also be a burden on the developer’s balance sheet, and many developers lack the skills and resources for credit assessment, loan monitoring, and follow-up on loan repayments. Also, many developers are not from the local community, so they lack some local knowledge and can exacerbate the challenges of this type of program. The main advantage of the second approach is that the developers can focus their time and resources on running the micro-grid, while their partner does the financing. However, it is often not easy to find financial institutions that are willing and able to lend to microentrepreneurs in remote rural areas on acceptable terms (i.e. reasonable collateral requirements and interest rates). This is particularly the case for start-ups or new business activities that have no track record.[9]

Micro-grid developers often use a lease-to-own model of equipment and in some cases residential focused appliance financing based on consumer finance or microfinance principles. Most financing terms are for 12 months or fewer, and they require the customer to make an up-front deposit of up to 30% of the cost of the appliance. The costs of electrical appliances vary but are typically within the range of most microfinance institutions (i.e. from a few hundred dollars to $10,000). In case of default, the equipment can be repossessed, or electricity can be disconnected, or the payment terms can be adjusted to incentivize the entrepreneur to make the necessary repayments. The customer usually makes repayments monthly, in addition to their monthly electricity payments. Therefore, the business case for PUE activities must account for both the cost of electricity and the monthly repayments. Ownership of the equipment transfers to the customer once the loan or lease is fully repaid.

3.4 Developer Operated Productive Use Businesses

Rather than just selling electricity, some micro-grid developers have chosen to set up their own productive businesses that rely on power from the micro-grid. These businesses are generally linked to existing local value chains, but they may also be completely new businesses.

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[9] Many microfinance institutions will require a business to have at least 6–12 months of cashflows before they will consider providing the business a loan. Some microfinance institutions will also require borrowers to start with smaller loans to demonstrate creditworthiness, which can delay access to loans that are large enough to purchase PU equipment.

Examples of micro-grid developers diversifying their income streams and running their own productive businesses include:

- Jumeme in the lake region of northern Tanzania (1 micro-grid, 90 kW) is milling imported maize to produce flour for sale to the local community, and using freezers to make ice for preservation of fish, both for local fishermen and to support their own tilapia fishing business
- Mandulis in northern Uganda (1 micro-grid, 32 kW) is milling maize to produce their own flour and as a service to local farmers, and selling byproducts of the biomass gasification process such as biochar which is a fertilizer and alternative to charcoal
- RVE.SOL in western Kenya (1 micro-grid, 7.5 kW) is treating water and selling water cannisters.

The main advantages for a developer of setting up its own PU business are:

- They have more control over the demand for electricity in the micro-grid, including the timing of demand so that they can co-optimize between their electricity sales and use as well as the growth of demand on their system.
- They can potentially make a higher margin on the PU business than on selling electricity. The PU business itself may eventually have higher growth and be more profitable than the micro-grid itself.
- They can reduce regulatory risk because the sale of services, such as milling, are less regulated than electricity in many countries. This doesn't reduce the developer's regulatory requirements in the electricity sector, but it can support diversification of revenue and thus reduce the overall risk from changes in electricity sector regulations.
- Diversification of funding streams, electricity sales and the identified PU, while potentially optimizing local staff members who can take part in both businesses.

The main disadvantages of a developer setting up its own business are:

- The cost of setting up and running the PU business may be beyond the financial means of some developers for some of the more expensive PU opportunities, such as water treatment systems or commercial ice makers.
- Increased technical and business complexity may undercut the company's ability to perform their primary responsibility (the provision of energy services) successfully.
- The developer may not have the local skills, experience, or knowledge to run the business.
- The economic benefit of the PU goes mainly to the developer rather than to the local community.
- Competition between the developer's own PU business and other local businesses may create community tensions.

4 Developers: Business Considerations

PUs present many business model considerations for a micro-grid system developer as they can increase revenues and lower costs for an appropriately designed system or an existing underused system. However, they can also present significantly different considerations than residential loads in terms of tariffs, risks, system design and other key considerations. This section reviews some of these key considerations from the developer perspective.

4.1 Anchor Load Model

The ABC micro-grid developer business model, which is what many developers targeted initially, focuses on larger anchor clients. “A” refers to *anchor* clients, which have large consumer loads and are responsible for a majority of the micro-grid’s electricity sales. They can potentially generate more stable, predictable long-term revenues for the micro-grid, making financing easier. Examples include cell phone towers, flower farms, tourist lodges, and other medium-sized industries and agriculture processing activities. “B” refers to smaller *business* customers, including agricultural loads, small manufacturing loads, and commercial or retail loads. This report is focused on PUs from these types of loads. “C” stands for *community* customers, which are mainly private households and make up a small proportion of the micro-grid’s loads.

Most African micro-grids are in remote areas and do not have access to large anchor clients, and thus this model may not be generally applicable and is likely not a viable strategy to provide widespread energy access. While the lack of an anchor client makes financing more difficult, anchor clients generally insist on more competitive tariffs and often have onerous service requirements that the micro-grid may not be able to consistently fulfill. Small business and PU customers offer a more diversified customer base and greater scope for local economic development. These small businesses are the focus of this report and the considerations in this section, representing a modification of the original ABC business model and a more viable strategy to provide widespread energy access.

4.2 Payment and Tariff Models

Micro-grid tariffs should be set at levels that account for the ability and willingness of rural customers to pay. In many cases however, micro-grids require some form of subsidy so that the owner and operator can make a fair return on their investment, and the tariffs are affordable and acceptable for the user. To this end, the tariff, with an applied subsidy if relevant, must reflect the true cost of providing power for the micro-grid to be successful (Reber et al. 2018). Some PUs are particularly sensitive to the price of electricity and can be stimulated to use more power through appropriate tariff setting. Micro-grid tariffs also need to account for alternative sources of electricity, such as stand-alone solar systems and diesel generators. These alternative sources may be more or less expensive for a business than electricity from the micro-grid but may also have additional benefits or costs to both the micro-grid developer and PU owner. As an example, Table 1 shows an economic comparison between the price of diesel and electricity for a maize mill. For consistency, all the financial analyses for this report were done in U.S. Dollars. Tanzanian shillings were converted to U.S. Dollars using the exchange rate in March 2018 of 2,244 Tanzanian shillings to one U.S. Dollar. There are clearly additional considerations, such as the cost of both the diesel engine and electric motor, the different maintenance requirements for both approaches, and a reduction in the complexity and cost of the PU operator to operate a device that may not be central to their business, such as maintaining a diesel engine.

Table 1. Maize Mill: Energy Pricing Comparison

(illustrative information based on E4I data)

VARIABLE	VALUE	UNITS
Size of diesel power motor	15	horsepower
Diesel consumption per hour	3.2	liters (L)
Diesel price	0.99	$/L
Operational hours per day	2	hours
Cost of diesel per day	6.34	$/day
Size of equivalent electric motor	10	kW
Amount of power consumed per day to match the amount of maize milled per day	20	kWh
Equivalent micro-grid tariff required to compete with the cost of milling using a diesel engine ($6.34/20kWh)	0.32	$/kWh

This analysis illustrates the challenge that competing power options pose for a micro-grid developer, as the diesel and electric motor options for a maize mill have similar capital costs. As such, a developer must offer power at approximately $0.32 per kWh to be competitive with a diesel motor, which is far lower than the $0.50–$1.20 per kWh most developers currently charge. Alternatively, electricity from a micro-grid could offer a different value proposition to the owner of a PU business where they would pay more for electricity because of other co-benefits it might provide for their business, such as higher availability because their mill never runs out of fuel or lower operating costs from not needing to pay employees to service the engine or travel to purchase diesel fuel, which can be quite far in many cases. See Sections 6.2 and 7.1 for additional discussions of maize milling economics and a case study. These types of tradeoffs have led to several micro-grid tariff models including those discussed in Sections 4.2.1–4.2.6. Also see Reber et al. 2018 for additional information on tariffs and tariff considerations.

4.2.1 Standard Tariffs

Many micro-grid developers/operators charge a fixed rate per kWh for the consumption of electricity. This is the most simple and basic way to charge for power, simply involving a method of measuring consumption, either pre or post payment. Such tariffs can become more complicated as the per kWh rates vary by certain customer attributes, such as type of connection (e.g. residential or commercial), size of load, or location of load.

Different tariff or subsidy structures may also be designed to support specific customer classes, such as providing a subsidized base level of service for residential customers while requiring commercial customers to pay the full cost.

4.2.2 Day/Night Tariffs

One challenge with solar micro-grids is steering consumption to times of peak generation during the day and reducing the need for expensive storage or back-up diesel generators at night. PUs can be incentivized to consume more during the day through lower daytime tariffs and higher nighttime tariffs.

4.2.3 Flat Standing or Connection Charges

A standing or connection charge covers the fixed costs of micro-grid connection, including the ongoing cost of connection, the cost of meter readings and maintenance, and other charges. It is simply a charge for access to electricity. Standing charges are often targeted at larger PUs who may pay a lower consumption (per kWh) charge. Connection charges may also vary based on the rated power of the PU equipment, driven by the micro-grid's need to reliability supply these typically larger loads. Feedback from PUs on such charges have been mixed. Some businesses are unwilling to pay the flat charge if they do not consume power because they close, for example, during harvest or holidays or feel the rate is to high based on energy use.

Micro-grid operators also often charge flat rates for fixed amounts of load. While this applies less to PU, it is common in residential applications where, for example, a fixed monthly rate is set for two light bulbs and a cell phone charger regardless of actual kWh consumption.

4.2.4 Prepayments

Most micro-grids require customers to prepay for electricity. The more electricity customers consume, the higher the pre-payments needed. Electricity usage can be monitored through load or smart meters. Prepayments are usually recorded, cashless, and paid directly by the user if a mobile money transfer system such as M-Pesa exists, thus reducing the potential for financial impropriety (Energy 4 Impact and INENSUS 2016). The prepayment structures of most micro-grids could impact a PU business, especially in an earlier stage, as it could pose a cash flow or financing challenge to prepay this cost prior to receiving revenues from the business.

4.2.5 Fee for Service

Developers can generate revenues directly from sales of electricity units (in kWh) combined with a standing payment, or by bundling the cost of electricity into the cost of productive services or products. This so-called "fee for service" model can help the developer avoid difficult electricity regulations and other end-user financing issues where micro-grid operators can purchase their own PU equipment. The micro-grid operator invests in a workshop or service center and sells use of appliances (e.g. an electric mill or woodworking tools) or final products (e.g. flour from a mill or clean water from a water kiosk). Customers then pay a service fee, which covers the cost of using the appliances (return on investment, operating costs) and the cost of the electricity, or a price for the product. To be successful, it is important that the micro-grid operator understands the local value chain and can cover the up-front investment and operating costs.

4.2.6 Productive Use Zones

Distribution assets make up a significant part of the cost of a micro-grid. Depending on the physical geography of the micro-grid site, connecting certain households and businesses that are far away from the source of generation may not be feasible.

Some micro-grid developers have addressed this problem by creating special zones for small commercial electricity users located close to their generating units. This allows them to save on distribution costs, potentially provide higher service quality such as three phase power, and potentially generate additional revenues from business space rental income. Such special zones are also good for the commercial businesses because they have access to better amenities and more customer traffic due to multiple businesses concentrated in one area. For example, RVE.SOL established the KUDURA commercial center near its 8-kW solar hybrid micro-grid in Sidonge, Kenya, which has mobile money agents, barber shops, snacks and food outlets, water services, and businesses showing television or videos (RVE.SOL n.d.).

For the PU zone model to work, it is important that the generator or business zone be centrally located in the community, so the zone can become a market hub. Care should also be taken to ensure the zone does not compete with an existing community marketplace, which might lead to community tensions and boycotts of the new zone. Finally, it is important to establish the right pricing points for both the electricity and the business space rentals.

4.2.7 Consumer Choice and Awareness

Promotion of PUE and increased consumer awareness can sometimes, perhaps surprisingly, lead to a fall in demand for electricity from the micro-grid. As local businesses become more aware of the electricity cost related to larger appliances and longer hours of use, they may reduce their uptake of power from the micro-grid by looking for efficiency improvements or better time of day utilization. This does not necessarily mean they have reduced their overall power consumption. Rather, as E4I has observed from one micro-grid in Tanzania, businesses choose to use their own solar home systems during the day and switch to the grid in the evening or make use of diesel generators when diesel costs are lower than the equivalent tariff of the grid. Therefore, it is important that micro-grid developers account for the cost and service provided by competing energy sources when they prepare their pricing plans for different customers.

4.3 Demand-Side Management

Matching electricity demand with supply is critical. It is difficult for micro-grids to achieve this balance because demand can be volatile as a result of the relatively small number of customers, the seasonality of rural economies, and the modest financial means of customers. Demand-side management aims to shift demand from times of lower renewable resource availability to times of higher availability. For solar micro-grids, this means increasing energy demand during the day when generation is high and reducing it at night when power comes from battery storage or a back-up generator.

Demand management for PUs can happen through load scheduling (specific times for electricity supply in different branches of the micro-grid), tariff incentives (lower tariffs at times of higher/less-expensive supply of electricity), automatic disconnection of nonpriority loads at peak demand times, and installation of energy efficient equipment/appliances. For solar micro-grids, it is a matter of identifying which users can choose when they consume electricity. For example, electric mills consume power close to times of high solar irradiation (because they often dry their product in the sun before milling to achieve a better-quality, drier flour), so they can be incentivized through price changes to make minor shifts in demand. In contrast, restaurants are mainly active in the evening, and they are unable to shift their use to times with higher solar irradiation.

As part of a recent report on micro-grid tariffs published by NREL in support of Power Africa (Reber et al. 2018), some high-level analysis tools were developed to examine the impact of different load profiles on the levelized cost of energy (LCOE) for micro-grids in Africa (Li 2018). These tools were used to compare the LCOE of a residential-heavy and a business-heavy load profile to provide some high-level quantitative insights into the potential LCOE differences between these two types of load profiles in three different power system configurations. These two load profiles both consume 19,711 kWh annually, but the timing of that consumption varies as the business-heavy profile has more consumption during the day than the residential-heavy profile. Results from this analysis are summarized in Table 2. It should be noted that the business-heavy load profile results in reduced capital expenditures (CAPEX), operating expenditures, and LCOE values for all three system types. This shows that PUE can lower costs for micro-grid users and improve the business model for developers. Additional information can be found in Appendix B.

Table 2. Results of Comparison of the LCOE of Heavy Residential and Business Load Profiles

RESULTS SUMMARY	RESIDENTIAL HEAVY			BUSINESS HEAVY		
	Diesel only	**PV + battery**	**PV + battery + diesel**	**Diesel only**	**PV + battery**	**PV + battery + diesel**
Total life-cycle cost	$150,567	$161,616	$142,168	$138,876	$122,369	$114,136
Total CAPEX	$39,395	$112,383	$45,737	$29,037	$79,122	$44,565
Total operating expenditures	$111,173	$49,233	$96,431	$109,839	$43,247	$69,571
LCOE	**$0.90**	**$0.96**	**$0.85**	**$0.83**	**$0.73**	**$0.68**

4.4 Load Estimation

Sizing micro-grid systems is complex, and systems are often over or undersized as discussed in Section 2. Part of this complexity and sizing challenge can be attributed to the lack of data regarding load profiles from PUs in operating systems. As part of a separate Power Africa initiative, NREL partnered with Carnegie Mellon University and PowerGen Renewable Energy, a leading East African micro-grid developer, to analyze customer and consumption data from PowerGen's existing systems in Tanzania (Williams et al. 2018). Select data from this analysis is presented in Figures 5–8 and illustrates some key attributes of the PUs in PowerGen systems. Figure 5 shows the distribution of customers in a typical system: residential or home customers make up the majority of connections.

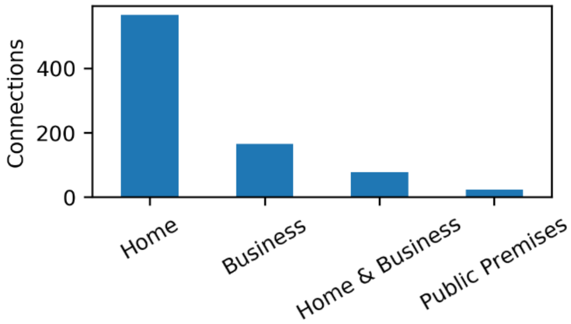


Figure 5. Distribution by customer types

Source: Williams et al. 2018

Figure 6 shows the typical employers and occupations of customers, which are primarily in agriculture or local business.

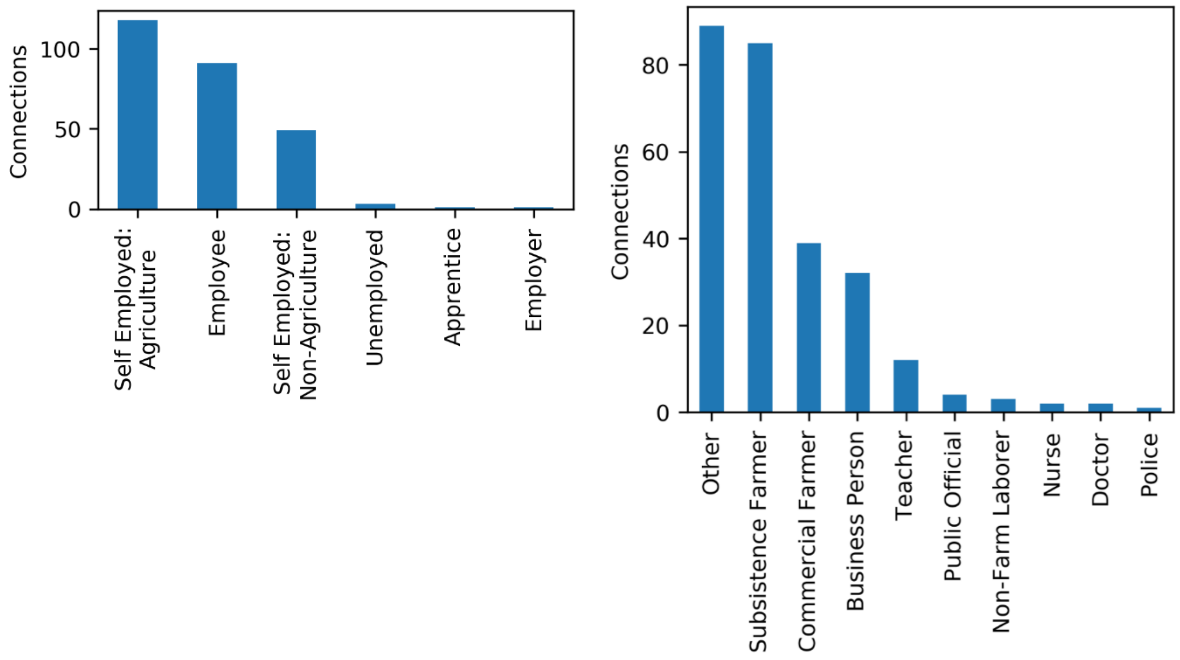


Figure 6. Distribution by customer employment

Source: Williams et al. 2018

Figure 7 shows distribution of customers by business type, with shops being the most common business.

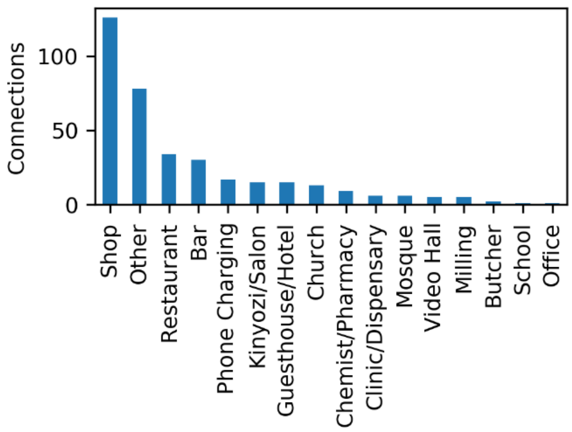


Figure 7. Distribution by customer by business type

Source: Williams et al. 2018

Figure 8 shows the average load profiles of various PU businesses. While residential customers make up the majority of the connections, Figure 8 shows that businesses have much higher consumption per connection.

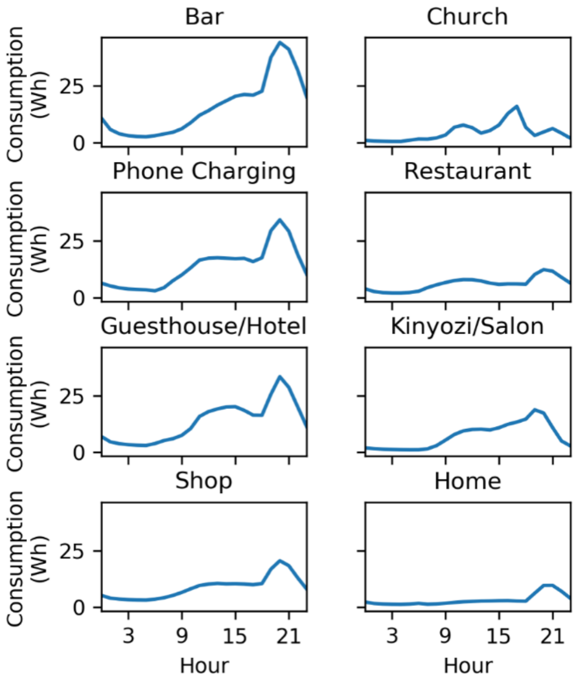


Figure 8. Productive use load profiles

Source: Williams et al. 2018

Actual load data of operating micro-grids have been shown to be a better predictor of future consumption than surveys in some cases (Blodgett et al. 2017). When designing micro-grids to incorporate PU loads, it could be valuable to compare survey data with these operational data to adjust or confirm estimates. Additionally, for developers considering encouraging PUs it could be valuable to review these load profiles and determine which types of business they may want to encourage based on when the loads occur. Finally, these data could be used to better understand what types of PU businesses are currently operating in rural villages and how they are operated.

5 Developers: Technical Considerations

While both developers and entrepreneurs have many considerations regarding how the PU of electricity may impact their businesses, developers also face a set of unique technical challenges when determining whether and how to connect these loads to their micro-grids. Consideration of how to connect PU loads can reveal concerns about quality and safety that result in high perceived risk. This section summarizes micro-grid levels of service, performance reporting and monitoring, and key technical considerations related to system design for PU.

5.1 Service Levels, Performance Monitoring, and Metrics

Governments, regulators, and donors are increasingly focusing on the level of electricity service provided by micro-grids. Just talking about energy access in terms of electricity connections is no longer sufficient; level of service matters. In Tanzania, for example, micro-grid developers are required to indicate the level of service they will offer at the project development stage, and this is then monitored throughout the project life cycle.

The World Bank/ESMAP[10] and the International Energy Agency have developed standardized definitions for different levels of service through a multitiered framework (Bhatia and Angelou 2015). Each tier has different levels of key attributes such as availability and reliability, with Tier 1 being the lowest level of service and Tier 5 being the highest and closest to grid quality. The QAF uses many of the same metrics as the multitiered framework and builds on this framework to address several additional metrics for performance monitoring and reporting and allows for disaggregation of the metrics.

It is important that developers of micro-grids define the service level that they will provide to productive users in terms of key metrics such as peak power, power availability, and reliability. Defining the service level helps the developer appropriately design their micro-grid system and helps the entrepreneur appropriately plan their business operations. A mutually agreed upon level of service can form the basis for a customer agreement between the developer and the business. See Lockhart et. al. 2018 for more information on customer agreements and key considerations. According to the multitiered framework, most PUs require Tier 3, 4, or 5 levels of service. The levels of service defined by the QAF are disaggregated into different levels for different categories and are discussed in the following as they relate to PU levels of service and performance monitoring.

Performance monitoring, metrics, and evaluation play an important role in the development and operation of micro-grids. The following bullets highlight key performance indicators and their impact on PU and discuss metrics for these items from the QAF. See Appendix C for more information.

- **Power Quality:** Electricity quality is typically measured in terms of voltage and frequency variations. The key question for PU customers is whether the power provided is of a sufficient quality to safely and effectively meet their needs. Most PU equipment cannot be operated properly if the voltage deviates from its design parameters. Larger PU equipment, particularly motors, can drive down the voltage and disrupt supply to other customers within the same feeder due to the high inrush or starting currents. Frequent monitoring of the system voltages and frequencies as well as testing transformers should make it easier to identify and solve power quality issues.

- **Power Availability:** Power availability is defined by three parameters: power draw, energy availability, and duration of daily service. The key questions for PU customers are whether power is provided in the amount that meets their expectations, is available for the specified duration and at an appropriate time of day. Depending on the service limitations of the micro-

[10] ESMAP is the Energy Sector Management Assistance Program, a partnership of the World Bank Group and others. For more information, see www.esmap.org.

grid technology, some developers have tried to incentivize PU businesses to operate in non-business hours through "time-of-day" tariffs and other methods.

- **Power Reliability:** A key issue for PU customers is whether electricity is supplied with enough reliability to meet their business needs. The reliability of micro-grids in sub-Saharan Africa is generally much better than that of national grids in the same region. Blackouts can significantly disrupt productive activities, leading to financial losses, the extent of which depends on the frequency and duration of the interruptions. Some PUs use costly backup generators to address this issue.

5.2 Technical Design

The load to be served is one of the most important considerations in the design of a micro-grid. The micro-grid must be designed to serve the required loads while maintaining power quality, reliability, and availability. To do this properly requires that decisions about key design requirements such as peak power, reactive power, single-phase or three-phase systems, and capacity utilization are made carefully. In this section, the report discuss how PU applications impact these decisions and how micro-grids can be safely and economically designed to supply PU loads.

5.2.1 Alternate Current (AC) versus Direct Current (DC)

When incorporating motor loads into micro-grid power systems, understanding how systems and motors are designed is important. Most micro-grid power systems in the developing world are designed as alternating current (AC) single or three-phase power systems; however, some systems are direct current (DC) systems.

- AC is the term used to describe an electrical supply where the flow of electrical charge (electric current) changes direction periodically. In most electrical supplies this happens 50–60 times every second. The voltage level also reverses along with the current. AC is suitable for delivering power to households and larger loads, including office buildings and PUs. Most micro-grids have AC-based distribution systems. Most larger scale power generation equipment including dispatchable generators, micro-hydro, and wind turbines above approximately 20 kW produce AC power.
- DC provides a constant voltage or current in one direction. It is produced by solar PV and is the form of power that is used in chemical battery storage. DC is suitable for common low-power household applications such as LED-lighting and TVs, and a few commercial applications such as variable speed drives in pumps.

AC can be converted to DC using rectifiers, and DC can be converted to AC using inverters. Rectifiers and inverters may be independent pieces of equipment or combined into one device, commonly referred to as a power converter.

Examples of DC micro-grid developers in East Africa include Devergy and Mesh Power. These developers have DC-based micro-grids that largely cater to households or small localized loads, such as water pumping.

The two most critical limitations of DC-based grids for servicing PU loads are:

- **Distribution Constraints:** DC-based distribution networks are generally not extended more than 200 meters from the generation point because of electrical losses. This typically does not work for most PU businesses as they are usually scattered across villages and may not be close to a centralized power source, though the PU zone as described in Section 4.2.6 is a notable exception. To extend DC grids beyond this limit requires large conductors or the use of high DC voltage, which introduces further safety and system complexity issues. Therefore, an AC-based distribution network is likely to be preferred for any large energy users or dispersed villages.
- **Appliances:** Most DC-based appliances are restricted to lighting and small appliances, so identifying DC based PU equipment may be difficult. The market for AC-based appliances is

more mature, with greater choice, availability, and lower prices. The continued expansion of DC based solar home systems is increasing the number of appliances that are being developed specifically for DC applications.

Most micro-grid systems provide AC rather than DC power because of the distribution and appliance constraints noted. Additionally, because centralized grids utilize AC power, people are more familiar with designing and building AC power systems.[11] Additionally the inability to use appliances and equipment from centralized grids and the sense from some consumers that DC power is inferior, has led to the more common use of AC micro-grids. However, DC micro-grids could certainly be used to power DC PU loads and could be a more efficient option, especially for small loads that can be placed near the point of generation.

5.2.2 Three-Phase versus Single-Phase Distribution Networks

Single-phase and three-phase networks are both used for AC-based micro-grids in Africa. There are technical and cost tradeoffs when deciding which to use. Single-phase power is sufficient for basic loads such as lighting, small electronics, and some small motors. Single-phase power is typically delivered with a two-wire system consisting of a power wire and a neutral wire. Three-phase systems typically supply power over four-wire systems consisting of three power wires and a neutral. Three-phase power is typically needed for any large loads, especially large motors. Three-phase systems can also deliver single-phase power by connecting between one of the power wires and the neutral. This allows a system to provide three phase power at locations close to the power station with individual single phase radial lines servicing outlying loads. However, the loads in a micro-grid system must be reasonably balanced between phases, which adds some technical complexity to systems design, distribution layout, and operations. A typical alternative is to provide individual single phase radial lines. Costs to build a three-phase system are typically slightly higher than a single-phase system; the exact cost difference depends on system specifics such as supply voltage and line distances, but costs are generally 5%–20% higher. Costs may be increased for items such as cables (four wires versus two), poles (heavier cables may require more poles), distribution boxes, and electrical meters. Costs for certain generation equipment, such as three-phase inverters or three-phase generators may also be slightly higher but are required for larger power systems as single phase, low voltage distribution lines also have defined load limitations. Additionally, supplying a business with three-phase power may be slightly more expensive, in terms of individual connection costs to account for additional protection breakers, than single-phase connections, which would still likely be provided at the residential level even for a three-phase micro-grid.

When large motor loads are added or desired in a micro-grid system, the decision between a single-phase system or a three-phase system becomes more critical. Single-phase motors require more current than three-phase motors, so as motors become larger, three-phase motors become more economical to operate and less expensive to purchase. Most motors above 5–10 horsepower require a three-phase power supply. Although specific residential consumers will typically only need single phase power, as micro-grid systems become larger and add PU, they are increasingly more likely to need to provide three-phase power to at least some consumers.

Given that three phase motors are readily available and may already be deployed in specific communities, many existing micro-grid system owners are examining ways to modify existing single-phase mini-grid systems to supply power to three-phase motors. When determining the best way to incorporate a three-phase motor into a micro-grid system, there are three main options: (1) replace the three-phase motor with a single-phase motor if available, (2) build a micro-grid or a portion of the micro-grid with three-phase generation and distribution capacity, or (3) use equipment such as a rotary converter or a variable frequency drive to convert single-phase power to three-phase power directly at the motor. For example, a variable frequency drive uses inverters and transistors to

[11] The cost effectiveness and efficiency of AC systems versus DC systems is an ongoing debate in the off-grid community. In this report, we do not take a position in the debate but instead focus on AC, as this is the most common design, especially for PU.

synthesize and output three-phase power from a single-phase source. Each of these potential solutions has tradeoffs in terms of cost, complexity, motor lifetime, and other considerations. For example, whether the motor and the micro-grid system are existing or just being developed will make a significant difference, as the economically optimal design for a new system versus a retrofit will likely be very different.

5.2.3 Dispatchable Backup Generators

A key decision for developers of micro-grids is whether to incorporate a dispatchable generator, typically diesel, or to rely on a purely renewable option that incorporates batteries and other load control options to provide consistent power from what is a variable resource. Dispatchable generators have many advantages, as they,

- Reduce the amount of storage required to provide high reliability while incorporating variable renewable resources, both on a daily and seasonal basis.
- Provides a viable second source for generating energy which provides additional flexibility in case loads are higher than originally expected.
- Help with equalization of batteries and thus reduce charging cycles and lengthen battery life for lead acid batteries which can result from inconsistent renewable based charging.
- Typically reduce the overall LCOE for a system providing a similar level of service when coupled with PV and batteries.

Diesel generators may not make sense for every situation as they also have many disadvantages, including:

- Increased system design and operations complexity.
- Additional maintenance skills required.
- Emissions of air pollutants and greenhouse gases.
- Requirements that diesel fuel be sourced, transported, and stored on-site which has additional operating cost, health, and safety considerations.
- Production cost of energy from diesel power is typically higher than the production cost of power based on renewable sources.

Diesel generators should be considered on a case by case basis that weighs the tradeoffs between these factors.

5.2.4 Lower Power Factor

Power factor is the ratio of the real power that is used to do work and the apparent power that is supplied. Depending on the origin, condition, and specifications of the PU equipment, PUE loads can sometimes cause low power factors either locally or throughout the micro-grid system because of their reactive power demands. A micro-grid system must be designed to both supply the necessary reactive power for these loads and the correct power factor if needed. Low power factor increases system losses and maintenance requirements, while reducing the operational life of specific equipment. A low power factor can directly or indirectly result in poor power system performance and reduced reliability. Power factor can be improved by installing corrective devices such as capacitor banks on the distribution system or at specific loads. However, the best way to avoid power factor issues is to appropriately select and size appliances and equipment. Low power factor and the need to supply large amounts of reactive power can also jeopardize the business model of micro-grid operators as they are typically not compensated for reactive power or the losses associated with poor power factor that may result from the poor selection of low quality equipment by a consumer.

5.2.5 Reliability

Large PUE loads can put additional strain on micro-grid power systems, which may impact both the PUE load and other customers. Several possible issues to be aware of include:

- If there are heavy users on an overloaded feeder, the feeder may be vulnerable to shutdowns.
- Users may occasionally connect loads greater than their maximum allowable energy consumption.
- PUE loads can cause low power factor in the micro-grid system resulting in inefficient operation.
- The starting or inrush current for PU equipment, specifically large motors, may be larger than the micro-grid can supply.
- System size may not be sufficient to supply the energy requirements of specific PU loads.

All of these issues can be mitigated with appropriate micro-grid and PU design combined with good communication and contractual agreements between the energy supplier and the customer. An additional way to mitigate or reduce the potential impacts of large PU loads is by designing the distribution system so that interruptions can be isolated and not affect the entire grid.

PUE significantly influences the design of the system's capacity. Measurement of the micro-grid's capacity should be done across multiple service level tiers based on the number of PUE appliances that can be operated on the system. The system can theoretically be designed so that all PU loads can run concurrently. In practice, this rarely happens, and effective load management can be used to support more efficient system designs.

5.2.6 Inductive Loads

Many micro-grids, particularly ones focused primarily on energy access, are principally designed to serve smaller and straightforward loads, such as lighting, cell phone charging, and some small appliances. An example of a typical small household load has a peak of around 25 W made up of several 5–10 W LED light bulbs and an 8 W cell phone charger. A typical micro-grid has between 25 to 200 households connected, so there is diversity in terms of exactly when these loads are turned on based on individual household behavior even though there is consistency with general use (e.g. most households turn on lights at night but not at the exact same moment). Power draw from these types of loads is relatively consistent when turned on, and these types of loads do not have large surge capacity or reactive power requirements unless very poor-quality appliances are being used. PUs are typically larger loads with more unique requirements.

Many PU appliances for micro-grids are based on inductive loads such as electric motors. Inductive loads resist changes in electric current, and thus the measured current lags the voltage.

When designing a micro-grid, it is important to analyze these loads carefully, both in terms of their likely electricity consumption (in kilowatt hours) and their potential starting current (measured in watts). Tables 3–5 show the normal and start-up current for different types of electrical equipment.

The actual electricity consumption of motors is usually slightly higher than the parameters indicated on the nameplate, which do not account for the efficiency of the connected appliances. Consumption is further increased by the power factor, which is typically around 80% in these motors. The combined impact means these loads may consume about 30% more than their nameplate capacity.

Starting currents for electric motors can be three to four times their nameplate current for up to several seconds, depending on the inertia of the motor and the connected appliance. Low inertia machines (e.g. woodworking and welding tools) have start-up currents that last a few milliseconds. High-inertia machines (e.g. mills) can require several seconds. Table 3 shows typical power requirements for many PU loads. Devices, such as motor soft starters can be installed in front of the specific device to reduce or soften inrush currents, typically by increasing the length of the high current inrush.

Table 3. Electricity Consumption Patterns: Commercial and Retail Loads

TYPE OF EQUIPMENT		WATTAGE (W)	TYPE OF POWER SUPPLY REQUIRED	START-UP WATTAGE (W)
Popcorn maker		250–1,800	Three-phase	None
Fryer		1,200–1,500	Three-phase	3,600–4,500
Oven		1,000–4,400	Three-phase	None
Hair equipment	Hair dryer	500–1,000	Single-phase	None
	Blow dryer	1,500–2,500	Three-phase	6,500–9,800
	Hair clippers	10–20	Single-phase	None
Printing and photocopying	Computer	65–150	Single-phase	None
	Printer, scanner, photocopier	100–465	Single-phase	None
Freezer/refrigerator		700–1,400	Single-phase	None
Blender		300–600	Single-phase	900–1,800

Source: E4I Experience and Estimates

Table 4. Electricity Consumption Patterns: Small Manufacturing Loads

TYPE OF EQUIPMENT		WATTAGE (W)	TYPE OF POWER SUPPLY REQUIRED	START-UP WATTAGE (W)
Welding, compressing, flexing (curving wood)		1,040–5,000	Three-phase	2,100–3,000
Woodworking	Lathe	225–750	Single-phase	675–2,250
	Table saw	1,600–1,800	Three-phase	3,300–5,000
	Jigsaw	400–900	Single-phase	800–1,200
Tailoring		100–600	Single-phase	None

Source: E4I Experience and Estimates

Table 5. Electricity Consumption Patterns: Agricultural, Horticultural, and Aquaculture Loads

TYPE OF EQUIPMENT	WATTAGE (W)	TYPE OF POWER SUPPLY REQUIRED	START-UP WATTAGE (W)
Chilling/cooling	800–4,800	Single-phase	None
Drying	600–800	Single-phase	None
Pasteurization, separators, homogenizers	700–3,500	Three-phase	1,400–10,500
Incubating	200–6,000	Three-phase	600–18,000
Irrigation pumping	500–4,200	Three-phase	4,800–7,200
Pressing	1,500–4,800	Three-phase	3,000–9,200
Grinding	800–3,250	Three-phase	6,500–9,800
Milling	850–7,500	Three-phase	1,500–21,500
Packaging machine	250–3,000	Three-phase	None

Source: E4I Experience and Estimates

6 Entrepreneurs: Business Case Studies

In Section 3, the report discussed important considerations for entrepreneurs examining PU enterprises. In Sections 4 and 5 the report examined the important considerations for PU from the developer's perspective regarding technical and business model challenges. In this section, the report looks at the economic case for different PU microbusinesses primarily from the entrepreneur's perspective.

This section provides illustrative business cases for five different types of PU: ice making, milling, carpentry, egg incubation, and water treatment. The first four business cases are based on data gathered by E4I on PU customers in eight different village micro-grids in Kenya and Tanzania from November 2016 to April 2018. E4I supported the micro-grids by providing business and technical mentorship services to the PU businesses to increase uptake of electricity demand. The water treatment case is based on input from Healing Waters International.

The data have been anonymized to protect the identity of individual developers. Where possible, the data gathered from these micro-grids was compared with data from other micro-grids.

The results of the business cases should be treated with caution for several reasons:

- Each village economy has its own unique features, and they may not apply to other areas.
- The data cover only eight micro-grids over 18 months. It would have been preferred to rely on data from more micro-grids over a longer period, but such data was unavailable.
- E4I was unable to get a reliable breakdown of the costs of the different PU businesses (apart from the electricity costs) and therefore relied on the aggregate numbers provided by the entrepreneurs. Ideally, a detailed breakdown for the different PU businesses on both revenue and costs, including information about size and pricing in the relevant PU markets, input costs (raw materials such as water, grains, timber, and eggs), electricity costs, and other costs (e.g. transport, rent, salaries, spare parts, and repairs) would have been available.

For these business cases, the analysis assumed an average tariff of $0.90 per kWh, which is a common median rate. The actual micro-grid tariffs for PUs vary enormously (from $0.50/kWh to nearly $2/kWh), depending on whether the consumer pays a fixed standing charge (in which case the price per kWh is lower), the type of PU business, and the size of the micro-grid.

6.1 Ice Making

Ice making can be an attractive PU activity, especially in remote and hot areas. There are two main types of ice makers: stand-alone freezers (which usually require less than a kilowatt of power) and much larger, commercial ice makers (which require 10s of kilowatts). The ice is used for a range of purposes but particularly to preserve food (e.g. store freshly caught fish) and cool drinks. Ice is typically sold in bags of 5–10 kg that cost up to $0.20 per kg.[12] The profitability of an ice-making business depends on the cost of electricity, the demand for ice,[13] and the availability and cost of alternative ice suppliers.[14] The business case for a freezer-based system is shown in Table 6. It assumes a price for ice of $0.20 per kg.

[12] E4I data and experience.

[13] For example, regulatory restrictions on fishing have reduced demand in parts of Lake Victoria, and there are also seasonal variations in fishing.

[14] Prices on islands tend to be higher due to less competition from nearby ice makers and the cost of shipping ice from the mainland.

Table 6. Business Case for a Freezer Based Ice Making System

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Size of freezer	90	L
Power rating of freezer	180	W
Amount of power consumed per day	0.36	kWh
Capital cost	365	$
Operational hours[a]	2	hours
Avg. Revenue of cold storage sales (cold drinks, ice cream, ice blocks) per month	110	$/month
Avg. Expenses per month (incl. electricity)	75	$/month
Cost of power	8	$/month
Tariff	0.90	$/kWh
Net Profit	**35**	**$/month**
Profit Margin	32	%
Simple payback for freezer	10[b]	months

[a] Freezer operates for eight hours; compressor cycle period is two hours. This may not represent the ideal operation of a freezer from a business perspective but is indicative of current operational practices. The business/freezer is assumed to operate 24 days per month or roughly 6 days per week.
[b] Simple payback is calculated as total costs divided by monthly profits or in this case ($365/$35)

It should be noted that this illustrative example and the others in this report do not include the cost of financing when analyzing profits and simple paybacks. The effective interest rates for developers or microfinance institutions could meaningfully decrease these margins and increase payback periods. The interest rates for this type of financing vary substantially and are not included in this analysis but should be considered by an entrepreneur looking at a business in this space. For example, if the $365 cost of the refrigerator was borrowed on a one-year loan with a 15% interest rate, the entrepreneur would end up paying about $30 over the course of the year in interest. Additionally, the monthly payments would be about $33 per month (including principal and interest) in this scenario, so the majority of the operating profits from the first year of business would be required to pay back the loan for the freezer, leaving limited resources for expanding the business, inventory, repairs, and other expenses.

Figure 1 shows a picture of a small freezer. Figure 9 shows an example of a commercial ice making operation powered by a micro-grid to supply ice to fishermen and businesses.

Figure 9: Commercial ice making equipment

Source: Samuel Booth, NREL

6.2 Milling

The milling of maize, cassava, or sorghum to produce flour, and the husking and shredding of rice are common in remote rural communities in Africa. Milling has traditionally been done through grinding or pounding by hand, because of a lack of electricity in rural areas, or by small mills driven by diesel engines.

The decision to invest in a mill depends on several factors:

- How much people are prepared to pay for machine milling: Milling fees, which are usually the only source of income for a miller, tend to be much higher (up to four times higher) in rural villages than in towns. Although the higher costs in villages must be weighed against the time and cost of traveling to town.
- How many people are prepared to pay for the milling service or how much grain will be milled.
- How much grain needs to be milled to pay off the mill.
- How much it costs to run a mill: It is important to cover both fixed and variable costs when calculating the cost to operate a mill.
- Whether there are competing mills in the same area: Based on E4I's experience, most small villages can probably only economically support one or two mills.

Diesel-driven mills are the most common type of mills. The two predominant business models for these mills are milling services for a fee (Table 7) and purchasing raw commodities such as maize kernels, milling it and selling flour (Table 8).

Table 7. Mill: Diesel-Based Operations (Milling Services Only)

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Diameter of the mill	18	inches
Size of the diesel generator	15	horsepower (hp)
Diesel consumption per hour	3.2	L
Diesel price	0.99	$/L
Average daily operation	2	hours
Amount of maize milled in one hour	120	kilogram (kg)
Price of maize milling	.045	$/kg
Cost of diesel per day	6.34	$/day
Labor cost	3.12	$/day
Revenue from milling per day	10.80	$/day
Net Profit after Labor and Fuel	**1.34**	**$/day**

Table 8. Mill: Diesel-Based Operations (Processing and Selling Maize)

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Diameter of the mill	18	inches
Size of the diesel generator	15	hp
Diesel consumption per hour	3.2	L
Diesel price	0.99	$/L
Average daily operation	2	hours
Cost of raw maize	0.36	$/kg
Amount of maize milled in one hour	120	kg
Price of processed maize	0.45	$/kg
Cost of diesel per day	6.34	$/day
Labor cost	3.12	$/day
Revenue from processing per day	21.6	$/day
Net Profit after Labor and Fuel	**12.14**	**$/day**

Within these two models, milling services are more common, but selling flour is more profitable. It was unclear why selling flour was not more common because it was vastly more profitable than milling services. Data were unavailable on the additional costs of running a business to sell flour and as such were not captured in this analysis, so that could be one explanation. The capital or financing costs associated with the purchase of the mill and generator were also not accounted for in these simple calculations. Other explanations may be related to the availability of maize for processing or the market demand for flour that make this a less viable option in practice. When determining to invest in and operate a milling business, an entrepreneur must not only decide on a business model, but they must also choose between an electric mill and a diesel-powered mill. Figure 10 shows an example diesel powered milling machine.

Figure 10: Diesel powered milling machine

Source: Samuel Booth, NREL

Electric motor-driven mills can be preferable to diesel-driven mills because they can be easier to operate and more reliable. They require less maintenance, are easier to start, and have environmental benefits. They also never run out of fuel and reduce labor by removing the time and cost of traveling to purchase diesel fuel. A cost assessment comparing a diesel mill to an electric mill was provided in Table 1. In this example, if the electricity costs less than $0.32 per kWh the mill would be less expensive to operate with electricity. This however does not take into account the other possible benefits. The profitability of a mill, diesel or electric, ultimately depends on the price of the grains, droughts and pests affecting food production and income generation, equipment breakdowns, and of course, the cost of electricity or fuel.

Many millers already have diesel-powered mills, and they may well decide to convert their mill to electric motors rather than purchase a brand new electric mill. The up-front investment in electric motors is much lower (around $500) than the full electric mill (around $2,000)[15], and the payback period is much shorter. However, there are a few challenges with retrofitting a mill for an electric motor. One example is that selecting an appropriate electric motor can be complex as it must conform to certain standards and specifications to avoid the risk of damaging the mill and potentially the micro-grid. In contrast, many electric mills have already been designed to meet certain technical, safety, and efficiency requirements.

The analysis for this report considered the business case for an electric mill rather than an electric motor for an existing mill. This analysis builds on the diesel mill case studies in Tables 7 and 8 to show the equivalent case for an electric mill. The analysis goes further to show the necessary tariffs required for a micro-grid to maintain the same level of profitability as the diesel mill and the breakeven tariff for the mill to make a profit assuming no other changes. These cases (Tables 9–10) do not consider savings for operation and maintenance (O&M), time required to source fuel, or other variables. Table 9 shows that the margins on a fee for service mill are small and an electric mill becomes unprofitable at a relatively low tariff of $0.38 per kWh. For the case shown in Table 10, where the mill sells flour, the profits are higher, and the business owner could adsorb higher cost energy up to a tariff of $0.92 per kWh. Although the breakeven costs for replacing a diesel driven option remains at $0.32 per kWh. With the E4I data showing an average micro-grid tariff of $0.90 per

[15] The cost of an equivalently sized diesel-powered mill is about the same, approximately $2,000. Data on the cost of purchasing a replacement diesel motor, instead of an electrical motor, was not available.

kWh in the eight micro-grids evaluated, careful consideration must be given for the ability of a mill to operate profitably on micro-grid power and the need for potentially lower tariffs to attract and retain mills as micro-grid customers. It is also necessary to further investigate the other benefits noted for electrical mills and their impact on the business case.

Table 9. Mill: Micro-Grid-Powered Operations Milling Services

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Size of equivalent electric motor	10	kW
Amount of power consumed per day	20	kWh/day
Revenue from milling per day	10.80	$/day
Labor cost	3.12	$/day
Net profit to be maintained (diesel-based case)	1.34	$/day
Desired cost of power	6.34	$/day
Breakeven Tariff for Diesel Cost Equivalence	**0.32**	**$/kWh**
Breakeven Tarif for Profitability	**0.38**	**$/kWh**

Table 10. Mill: Micro-Grid-Powered Operations Processing and Selling Maize

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Size of equivalent electric motor	10	kW
Average daily operation	2	hours
Amount of power consumed per day	20	kWh
Revenue from milling per day	21.6	$/day
Labor cost	3.12	$/day
Net profit to be maintained (as per business as usual)	12.14	$/day
Desired cost of power	6	$/day
Breakeven Tariff for Diesel Cost Equivalence	**0.32**	**$/kWh**
Breakeven Tariff for Profitability	**0.92**	**$/kWh**

6.3 Carpentry

Carpentry and other woodworking activities are widely practiced in rural communities in Africa. In a similar way to how millers operate, carpenters often operate manually without an electricity connection by traveling to an electrified location or using diesel generators. Except for some saw mills which can be driven directly from a diesel engine, carpentry or other woodworking businesses will typically use electrical energy which lends itself more to the use of micro-grid solutions. The success of the carpentry business depends on demand for furniture and other wood products, the availability and cost of timber, and the level of competition. Based on E4I's experience, most small villages can probably only economically support one or two carpenters and woodworking shops. The electric machinery used by carpenters ranges from small drills and grinders to large machines, such as bench saws, which are more expensive and have larger power requirements. Limited information about the business case for carpentry was available, but the reference business case for a lathe machine is shown in Table 11.

Table 11. Business Case for Carpentry Tools

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Capital Cost	1050	$
Assumed revenue	245	$/month
Assumed cost	150	$/month
Energy consumption	18	kWh/month
Net profit	**95**	**$/month**
Profit margin	**39**	**%**
Simple payback	**11**	**months**

Especially in the case of the more expensive PU appliances such as mills or machine tools, the cost of financing must be considered. In this case, if the $1,050 was borrowed at a 15% interest rate with a one-year term, monthly payments for principal and interest would be about $95, so the business would have a significant cash constraint during the first year of operation while the profit was being used to pay back the loan. However, a two-year term would allow for payments of about $50 per month and a much more favorable operating environment for the business owner. Typically, the terms for loans are determined by the lending institute or entity.

Figure 11 shows an example carpentry workshop with saws, drills, painting machines, and other tools powered by a micro-grid.

Figure 11. Example carpentry workshop

Source: Samuel Booth, NREL

6.4 Egg Incubation

Many households in Africa keep chickens for eggs and meat. Incubators can allow households to hatch more eggs than a hen could (they allow a hen to lay more eggs rather than incubating eggs, as during incubation hens stop laying eggs), but they require electricity. A hen can hatch about 20 to 30 chicks per year but using the same hen with an incubator one could get up to 300 chicks per year (Sure Hatch 2018). Egg incubation can be an attractive business for rural villages because of its low up-front investment cost and potentially high returns. The success of the business depends on demand for and supply of eggs and chicks, proper use of the incubation equipment, the quality and fertility of the eggs before incubation, and the level of competition. The business case for an egg incubator is shown in Table 12. Figure 12 shows example egg incubation equipment.

Table 12. Business Case for an Egg Incubator

(illustrative information based on E4I data)

VARIABLES	VALUES	UNITS
Size of incubator	100	eggs
Power rating of incubator	100	W
Capital cots	122	$
Operational hours	24	hours/day
Amount of power consumed per day	2.40	kWh/day
Operational days per month	21	days
Tariff / Cost of power	0.90	$/kWh
Cost of power	45	$/month
Avg. Expenses per month (including electricity)	83	$/month
Avg. Revenue of sales per month	125	$/month
Net profit	**42**	**$/month**
Profit Margin	**34**	**%**
Simple payback	**3**	**months**

In this case, the cost of the incubator is $122 and financing or the capital cost of the incubator is not included in the average expenses. It should also be noted that power with a high level of service is an important factor in an egg incubation business, which lends itself to supply from a micro-grid power system as compared to utility power or power from a personal or community diesel engine.

Figure 12: Example egg incubation equipment
Source: E4I

6.5 Water Treatment and Sales

Clean water for drinking, cooking, and hygiene is essential for sustainable development in rural Africa. The many methods of treating water in rural areas include chemical treatment, reverse osmosis, and filtration. In addition to water pumping, many of these methods require electricity to power treatment equipment, which provides great opportunity to co-optimize the production of electricity with the provision of clean water. A case study of this application and the potential business opportunity was developed for this report in cooperation with Healing Waters International.[16] Healing Waters International supplies compact water treatment solutions to Jibu, a company that helps provide clean water in East Africa by working with local entrepreneurs.[17] This case study was based in part on information gathered from Jibu's experience. The case study focused on a representative remote village in Uganda using a Solar Pure Ultrafiltration UF system from Healing Waters powered by a micro-grid to produce and sell clean water at a village kiosk. A summary of the business case for water treatment and sales is provided in Table 13. Additional information can be found in Table A4-3 in Appendix D.

Table 13. Key Data Inputs for Water Treatment Modeling
(illustrative information based on Healing Waters data)

LOCAL WATER DEMAND VARIABLES	VALUES
Number of households in village	200
Average household water use per day[a]	12 L
Total commercial use per average day assuming one bar, restaurant, clinic, and school	240 L
Total water demand per day	2,640 L
WATER TREATMENT EQUIPMENT VARIABLES	
Plant Capital and Operating Costs	
Ultra-filtration water treatment system	$10,500
Additional costs for other infrastructure, customs, installation, etc[b]	$9,100
Total system installed cost	$19,600
Store operating hours per day	10
Plant operating hours per day (1,800 L/hour capacity)	2
Plant power demand	400 W
Additional shop power demand	25 W
Total electricity use per year	383 kWh
Tariff / Cost of power	$0.90/kWh
Plant Electricity Costs per Year	$345
Plant O&M costs per day	$47
Plant Revenues and Financials	
Water price[c]	$0.06/L
Annual revenue from water sales[d]	$57,658
Annual costs for operations	$17,573
Annual profit	$40,085
Profit margin	70%
Simple payback	4 months

[16] For more information, see http://www.healingwaters.org.
[17] For more information, see jibuco.com.

[a] Estimate is a conservative average based on Healing Waters experience and is consistent with World Health Organization information (Howard and Bartram 2003).
[b] Costs for these items will vary by system and country.
[c] Current prices in Uganda range from $0.06/L to $0.14/L.
[d] Assumes a full willingness to pay from villagers and a conversion of water needs for drinking, cooking, and other uses to water sourced from the treatment plant. This is consistent with Healing Waters experience but would require additional analysis from a prospective entrepreneur.

The scale of the investment in terms of capital costs for the water treatment equipment is much higher than other potential businesses such as egg incubation, e.g. ~$20,000 versus ~$100, but the profit margins are higher, and the simple payback is similar. With a system cost of this size, financing would likely be required which would reduce profitability and extend the simple payback. Additionally, a higher level of skill from the operators would likely be required to run a water treatment plant over an egg incubation business. Given the need for clean water and the additional economic and health benefits provided by access to clean water, the co-optimization of energy and water production appears to have large potential and deserves further analysis. Figure 13 shows clean water produced by a Healing Waters treatment system filling bottles.

Figure 13: Healing Waters treatment system and bottle filling

Source: Healing Waters International

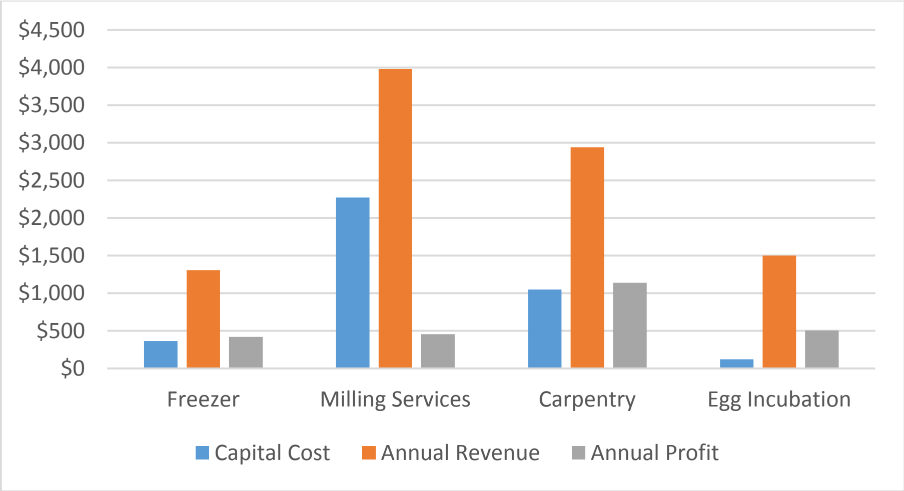
6.6 Other Productive Uses

Many other PUs are not illustrated by these business cases. Some other common examples can be found in the PowerGen data in Section 4 (Williams et al. 2018). Additionally, other common uses have not been discussed or researched to date. For example, welding machines are common in many villages in Africa where they are used to repair milling machines, bicycles, and other items. Welders use large amounts of power over short periods, so they would require careful consideration as to the value proposition of connecting them to micro-grids.

Though this report is not an exhaustive list of PUs and it covers only a small fraction of the potential options for micro-grids, it does present a common framework through which options can be compared.

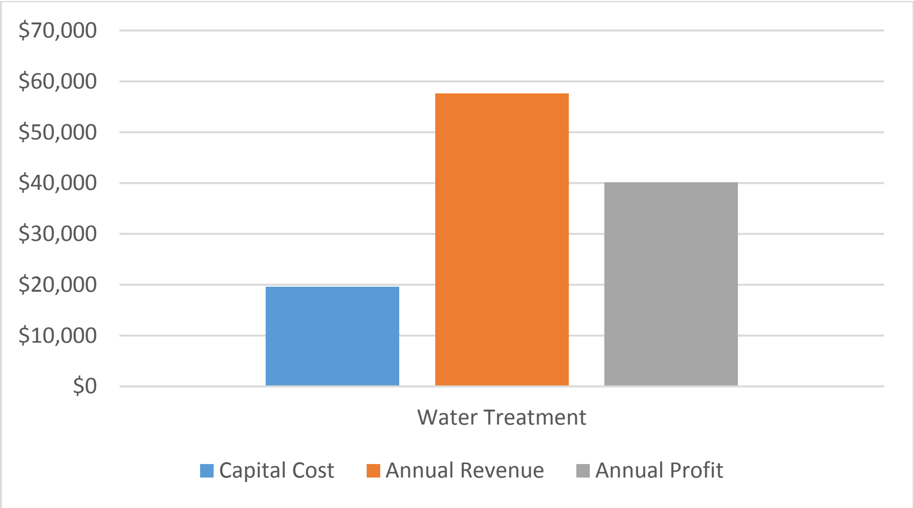
6.7 Business Case Comparison

Figures 14 and 15 compare the initial investment requirements and financial performance of several different PU business cases and their monthly electricity consumption. For developers, the figures show which of the PU opportunities considered have high investment requirements and the likely cost of promoting different PUs through the provision of equipment to business owners. The figures also show the electricity demand for the different equipment, which helps inform the anticipated installed capacity of the micro-grid. For entrepreneurs, the figures show the expected investment cost for the different PUs compared to the anticipated monthly sales and net profit. The figures also increase awareness among entrepreneurs of the likely range of power consumption for different appliances, which allows them to start thinking about how to consume electricity more efficiently.



Note: annual profit does not include recovery of capital cost

(illustrative information based on E4I data)



Note: annual profit does not include recovery of capital cost

(illustrative information based on Healing Waters Data)

Figure 14. Investment requirements and financial performance of different Pus

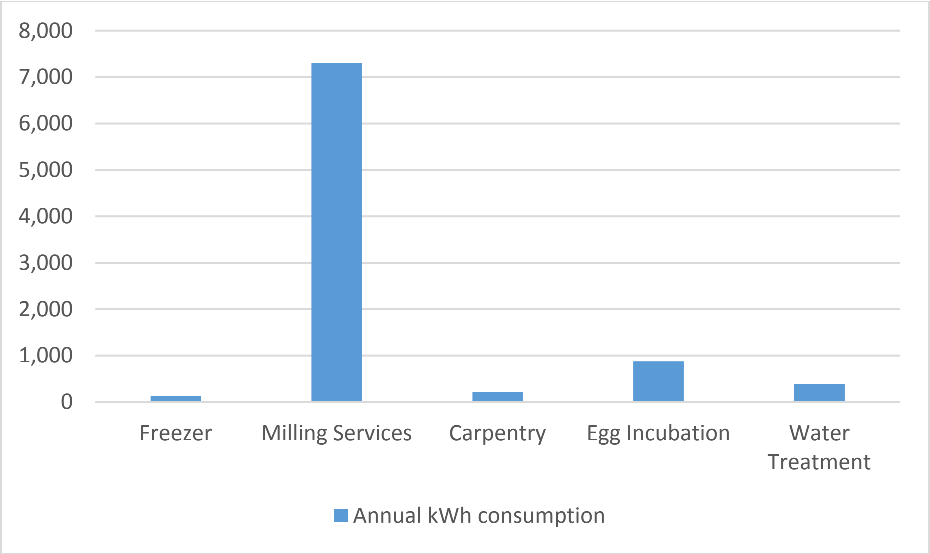


Figure 15. Electrical consumption of different PUs

(illustrative information based on E4I and Healing Waters Data)

7 Impact of Productive Use on Micro-grids

Creating a sustainable revenue model to serve rural communities is a key challenge for the micro-grid sector. The cycle of growing demand, increasing revenue, and lowering costs through the addition of PUs hopefully results in a more viable micro-grid business model. PUs, generally being the largest consumers of electricity, clearly play a key role in contributing to the economic viability of micro-grids.

7.1 Financial Impact

7.1.1 Optimal System Design

When designing micro-grids, the specific characteristics of loads, such as timing, magnitude, and seasonality can have a large impact on the financial viability of the overall system. For this reason, the specific power requirements of a PU business may positively or negatively impact the design, operation and resulting costs of power. This impact may be especially pertinent for smaller microgrids where any specific PU may have an oversized impact. In the following section, the report looks at the potential LCOE impacts of supplying power to a specific PU under several different use conditions, demonstrating that how the PU is incorporated into a micro-grid application will impact the resulting benefit.

In a fashion similar to that described in Section 4.3, the analysis used NREL's base case model of a representative village in Tanzania developed previously for analyzing tariffs (see Reber et al. 2018) to compare the techno-economics of adding a 10-kW (sizing based on E4I data) maize mill to a new micro-grid. The design of the micro-grid to serve this load along with other residential and commercial loads using NREL's REopt (Renewable Energy Optimization) tool was analyzed. REopt™ is a techno-economic decision support model used to optimize energy systems for buildings, campuses, communities, and microgrids. REopt recommends an optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings and energy performance goals.[18] The analysis compared various operating scenarios for the mill with the base case to examine techno-economic impacts. The scenarios evaluated included the addition of a,

1. 10-kW mill operated on weekdays throughout the year for 8.0 hours per day from 9:00 AM to 5:00 PM with an average loading of 33% during operational hours: loading is the fraction of time the mill is operating over the course of operations during each day. In this case, the mill would operate for 2.6 hours each day at full load. It is useful to calculate overall energy requirements in terms of kWh that the micro-grid must meet while also ensuring the micro-grid can meet the 10-kW peak power requirements of the mill.
2. 2.5-kW mill with the same operations as mentioned previously (#1) to compare the impacts of size. It should be noted that E4I data indicate that mills operate for approximately 2 hours per day on average, while discussions with developers indicate that some mills operate more hours per day than this and some operate less.
3. 10-kW mill with the same operations as mentioned previously (#1) except that it is operated at 50% and 16.5 % loading in two separate scenarios.
4. 10-kW mill with the same daily operations as mentioned previously (#1) except that it is operated seasonally for either three months of the year (December to February) or six months a year (November to April) to coincide with the maize harvest season and to examine the impacts of seasonality in two separate scenarios.
5. 10-kW mill with the same daily operations as mentioned previously (#1) except with 50% loading from November to April to coincide with harvest season and at 16.5% loading for the rest of the year.

[18] For more information see, https://reopt.nrel.gov/.

These scenarios compare the techno-economic impact of mills on the final system life cycle cost of power for a micro-grid system that meets the requirements of size, loading, and seasonality. Figures 16–21 illustrate how the overall techno-economics of the system change under various scenarios. For simplicity, a final LCOE is provided to represent the relative cost of suppling power inclusive of the larger load while in an operating power system it could be that a PU operator is charged a higher tariff to make up for the need to supply a higher level of service to that specific PU. It is also assumed that the load from the mill is applied during weekdays between the hours of 9:00 AM to 5:00 PM. If a different load pattern was assumed, the results could be quite different. Details of the system costs and other economic parameters can be found in Appendix D.

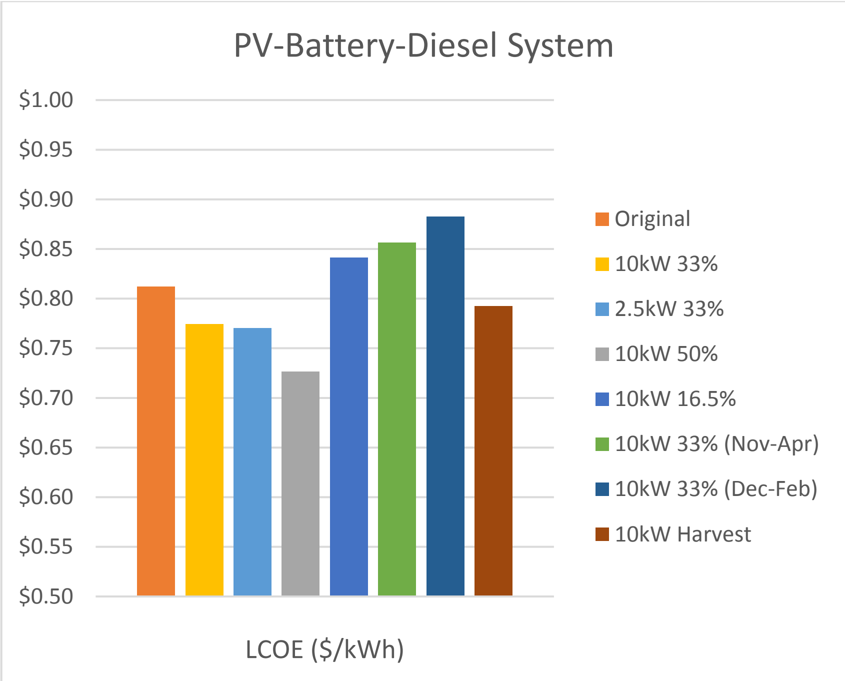


Figure 16. LCOE of scenarios for hybrid systems

Figure 16 shows how the LCOE of hybrid PV, battery, and diesel systems vary under the different PU mill loading scenarios. Some of these scenarios increase overall system costs compared to a system without the mill (the "original" case), while other scenarios reduce overall system costs. This clearly indicates the need for careful consideration of adding a mill to a micro-grid as the extra equipment costs must be balanced against the additional sales of power. The highest loading of 50% which corresponds to the highest capital costs (Figure 17) shows the lowest overall cost of $0.73 per kWh and indicates the potential of PU to lower system costs. Alternately the lightest loading of 16.5% increases costs over the base case from $0.81 to $0.88 per kWh since the micro-grid design is required to cover the high cost of supplying power to the mill even though it does not use very much power to defer the higher costs.

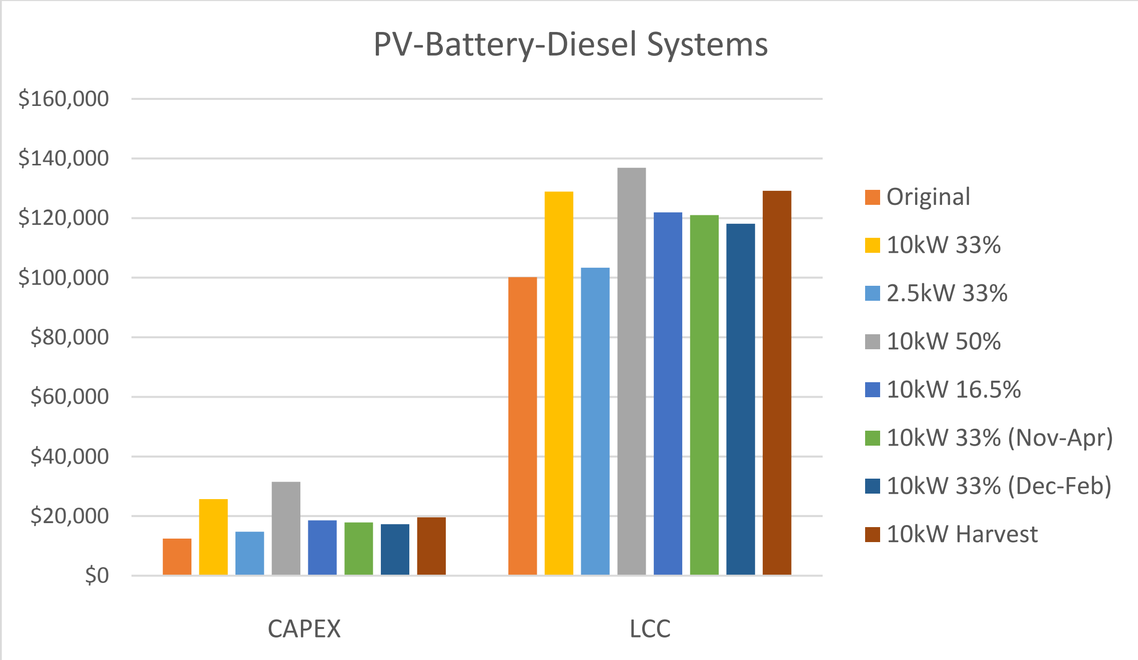


Figure 17. Capital costs and life cycle costs of mills scenarios for hybrid systems

Figure 17 shows how capital costs and life cycle costs change for these systems. Life cycle costs increase in all scenarios because additional load is being supplied. CAPEX increases in each scenario as well because the optimizer adds new generation sources to meet the mill load. However, the optimal generation mix changes based on mill loading with PV more favored at higher loading levels of 33% and 50% and diesel generators favored at lower loading, as shown in Figure 18, as it is more efficient to provide short duration, high load cases with diesel in place of PV and inverters. Lower levels of PV and higher levels of diesel use are also found with seasonal loading. Figure 18 shows the sizes of the generation selected.

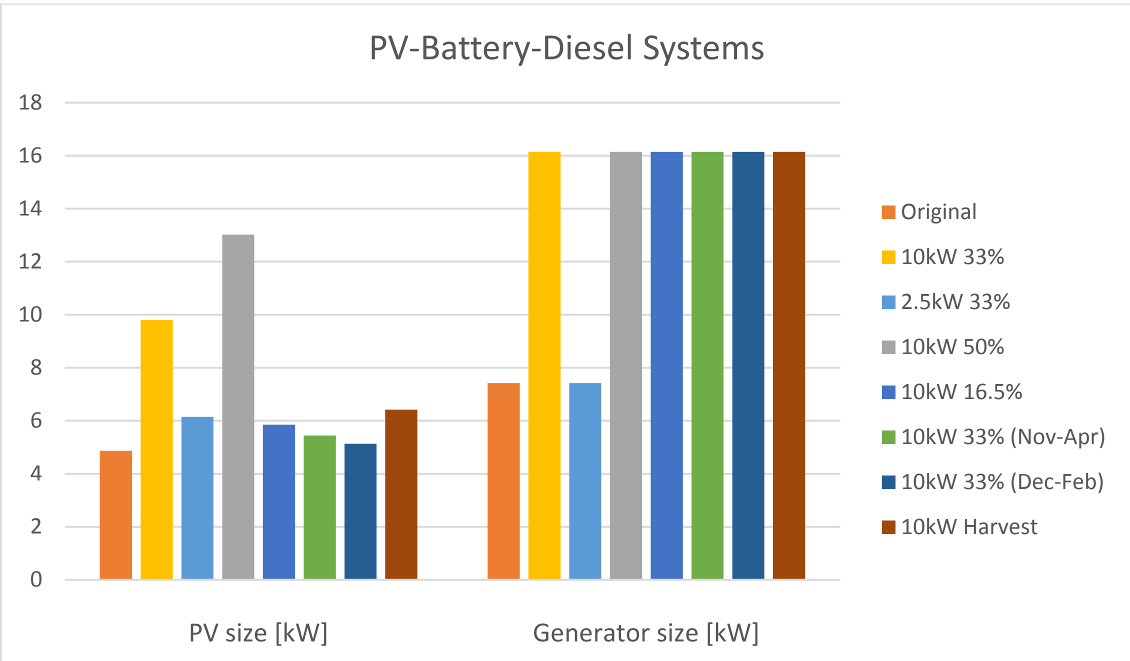


Figure 18. PV and generator sizing for hybrid systems

Figures 19–21 review the results of the PV and battery only scenario analysis. Figure 19 shows that LCOE impact varies again by milling loading with some scenarios lowering overall costs and some increasing costs. Figure 20 shows the capital and lifecycle costs, and Figure 21 shows the resulting component sizes.

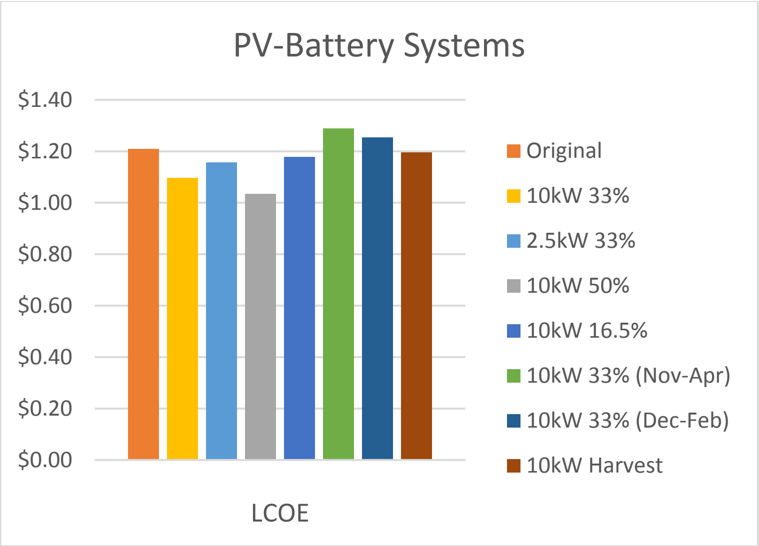


Figure 19. LCOE of PV-battery systems ($/kWh)

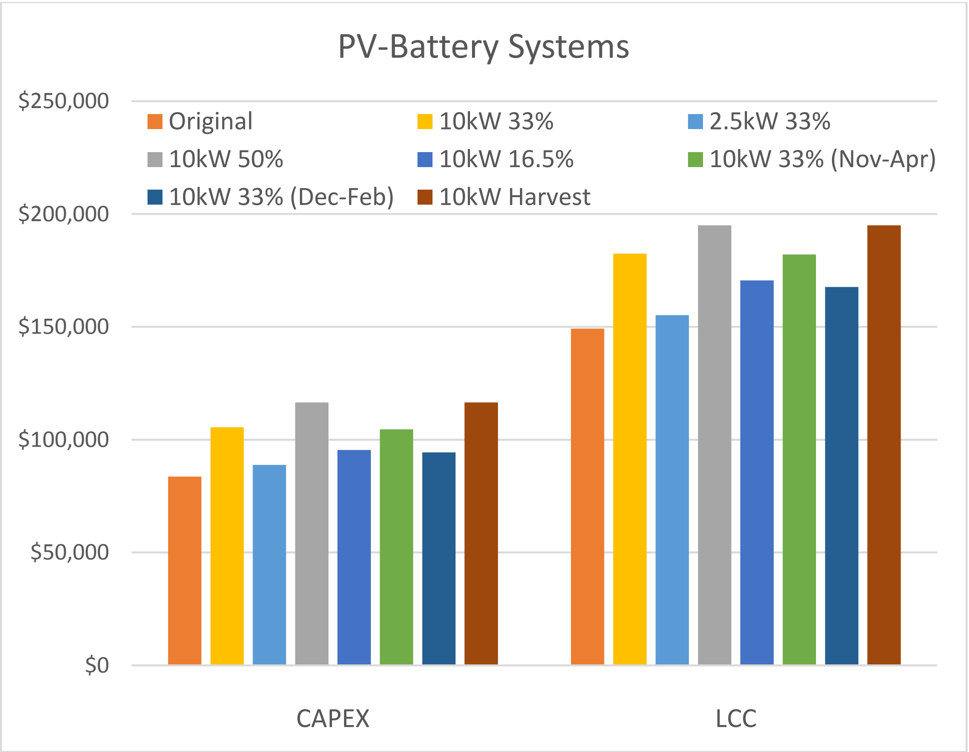


Figure 20. Capital cost and life cycle cost of PV-battery systems

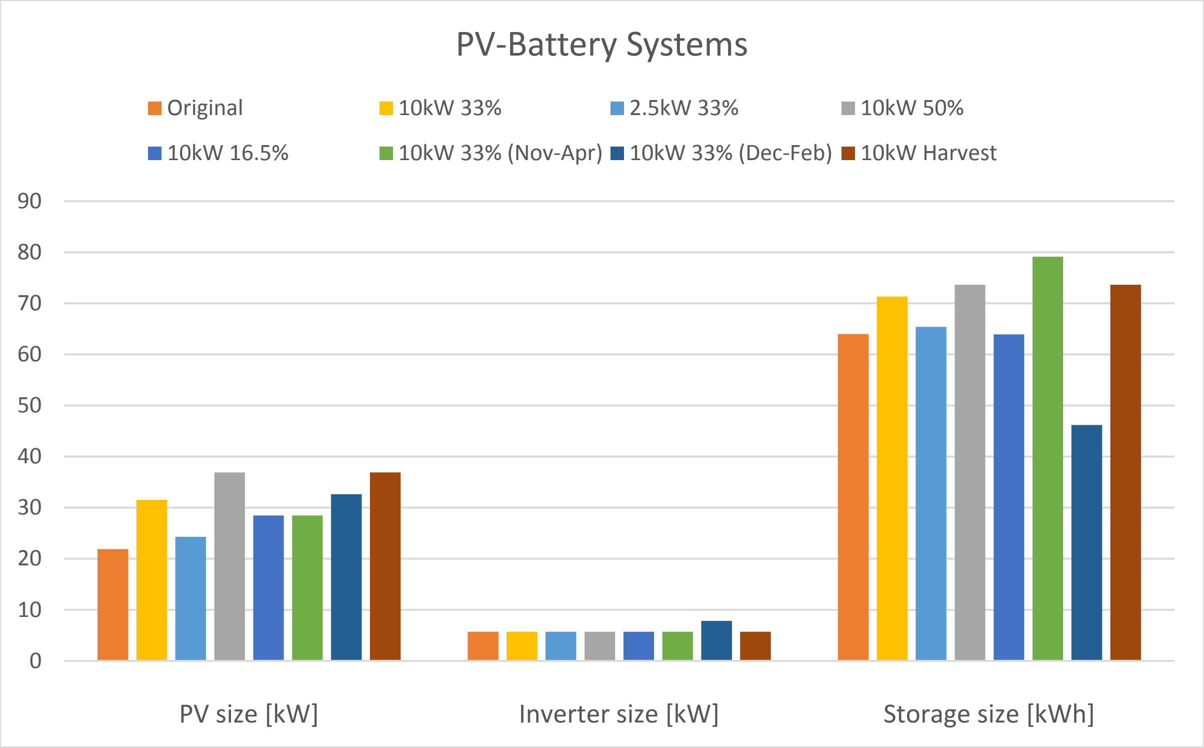


Figure 21. Optimal generation sizing for PV-battery systems

Overall the REopt analysis helps to illustrate the complexities of adding PU loads to a micro-grid in terms of their impact on the overall business model and costs. Careful consideration of loads is needed to understand their peak loads, average loads, and seasonality to determine their impact on key financial metrics like LCOE and capital expenditures and to determine if/how they should be connected to a micro-grid system and under what type of tariff. Also, the size and mix of optimal equipment changes depending on the loads; optimization is critical to make sure the equipment is properly sized for the PUE application.

7.1.2 Existing Oversized Systems

Based on E4I experience, it is common for many micro-grids currently operating in Africa to be oversized. This can be caused by many factors but a key one is poor demand prediction. Thus, a large fraction of existing systems operates far from the optimal design. A common response to address the underutilization of power systems is to work to expand the load, and encouraging the addition of PU loads is an approach that has additional local benefits. However, the ideal solution would be to appropriately size the system during the design phase. Adding PU loads can increase capacity utilization of installed but underused assets and improve revenues. Capacity utilization in this context is a measure of the potential generation capacity of the micro-grid compared with the actual sale of power to micro-grid customers. Having high levels of capacity utilization is especially important for micro-grids that include renewable energy generation sources as this generation has high fixed costs but low operating costs. Increasing the capacity utilization reduces the overall LCOE of the project as the fixed costs are spread out over a larger number of kWh of power sales. As was indicated in section 7.1.1 however, care must be taken to increase utilization at the appropriate time if possible. Expanding evening loads in a PV-battery system may increase the use of the batteries, resulting in capacity limitation issues. Adding additional loads that force the use of expensive diesel fuel may also result in increasing the overall costs of operating the power system.

7.2 Social Impact

Very little empirical research has been done on the social impact of PUE in micro-grids. This section highlights some expected social impacts, but many of these must still be validated. Furthermore, many of these impacts and benefits can only be realized if there is a strong local support network, including business mentoring, access to appropriate appliances, affordable finance, and access to markets.

7.2.1 Job Creation and Induced Impacts

Access to electricity can create jobs by helping existing businesses expand and new ones form (Akella, Saini, and Sharma 2009). Also, jobs created by PUs can have a multiplier effect as workers spend part of their income on the local economy, increasing spending in other sectors such as retail and leisure, which, in turn, can create additional "induced" jobs (EUEI-PDF and GIZ 2013). The multiplier effect may also help the local economy progress from traditional economic activities to more value-added ones such as processing and manufacturing.

7.2.2 Environmental Considerations

Access to clean power for PUs can potentially contribute to the mitigation of climate change. If productive power emerges from a renewable energy source, local demand and need for fossil fuels may be reduced, thereby reducing CO2 emissions. Renewable PUE can reduce a community's dependency on dangerous and polluting fuels such as kerosene or diesel fuel. For example, RVE.SOL's KUDURA center at its micro-grid in western Kenya led to a 72% reduction in kerosene usage in the local community (RVE.SOL n.d.), which led in turn to a 74% increase in disposable income19 (ARE n.d.). Further, the expansion of PUs within a community leading to the expanded availability of local products and services such as clean water, milled flour, or ice, reduces the transportation and fuel consumption impacts of bringing these products in from nearby communities.

7.2.3 Gender Equality

PUE can empower women through employment. However, the evidence to back up this theory is mixed. Studies in South Africa, Nicaragua, and Guatemala showed that women were 9%–23% more likely to gain employment outside the home following electrification. Electrification, generally through grid extension (although the results are likely similar for isolated micro-grids), saved women time and enabled them to complete domestic activities in the evening, thus allowing them to participate in paid work during the day. Electrification has also helped challenge gender norms, with women in India reporting an increase in autonomy, as measured by factors such as the ability to participate in household decision-making (EUEI-PDF and GIZ 2013).

E4I has found that female entrepreneur participation in its PU mentoring activities has been low. In previous E4I programs, only 27% of entrepreneurs were women. This is in part explained by the fact that these programs focused on existing businesses, most of which are owned by men in rural Africa. The programs also focused more on industries that are more likely to have male owners, such as manufacturing or carpentry. Most of the women were active in retail trade and services activities, while, these programs focused mainly on business activities in fishing, agriculture, agriculture processing, and manufacturing.

Given the considerations mentioned previously, it is important that any market engagement program is gender-sensitive and considers participation by women. Mentoring activities must be tailored to the specific challenges faced by women in accessing skills, capital, collateral, financial and technical literacy, asset ownership, product marketing, contacts throughout the value chain, saving and credit services.

[19] Percentage increase in disposable income after five years of micro-grid operation.

8 Risks and Mitigation Strategies

This section looks at the key risks and mitigation strategies related to the promotion of PU in micro-grids, excluding the technical risks covered elsewhere in this report.

8.1 Poor Estimation of Expected Demand from PUE

The main risk for a micro-grid developer in relation to the development of PU is in assessing the power needs of PU. Most developers overestimate the demand from existing or new PUE, leading to underuse of the micro-grid which is likely to drive up costs as was seen in Section 7.1. There are many reasons demand from PUs may not meet expectations. The demand assessments may be unrealistic, the entrepreneurs may lack the necessary skills and access to finance and PU equipment, or they may simply have limited appetite for risk because of a lack of information about market opportunities (GIZ and EUEI-PDF 2013).

There are several potential mitigation measures that can address this risk:

1. Gaining a better understanding of the specific drivers of PU within a community leading to the identification of specific PU focused programs such as providing business mentoring for the entrepreneurs and establishing PU information and demonstration centers.

2. Improve access to capital, such as through setting up a fund to provide grants or concessionary funding for the purchase of PU focused electrical equipment.

    a. For example, E4I made an agreement with a microfinance cooperative (Ukerewe SACCO) to provide loans to the PUs of Jumeme's micro-grid on Ukerewe island in Tanzania (Contejean and Verin 2017).

    b. E4I also partly guaranteed the loans to encourage the SACCO to lend to higher-risk customers that did not necessarily meet their borrowing criteria.

3. Another option is aligning or applying for support from local government or donor development programs that focus on economic development in rural areas (Energy 4 Impact and INENSUS 2016).

4. Developers may also be advised to take a more conservative approach to demand assessments; for example, by assuming only 50% of PU demand is likely to be realized.

8.2 Payment Risk

Payment risk is another challenge for developers. Some customers may be unable to afford the initial connection charge or ongoing electricity bill, and PUE are not immune to this problem. This is particularly the case in agricultural areas before the harvesting season, when financial resources are more limited (Manetsgruber et al. 2015) and expenditures in specific PU applications may be reduced even though the operating costs of a PUE may not be similarly reduced. Although less likely than when providing electrical service, some PU customers may be unwilling to pay because they are not satisfied with the electricity service, for example, because of metering or connectivity issues or because of unrealistic expectations about the quality and cost of service.

There are various mitigation strategies for payment risk.

1. Most micro-grid operators operating in remote rural areas require their customers, both residential and commercial, to pre-pay for a certain service or level of consumption, usually one month in advance (see Section 3 for more information). While this addresses the short-term payment risk, it cannot guarantee the long-term revenues of the micro-grid and may be a barrier to entry for some energy intensive PUE.

2. Because PUE are typically high energy users, mechanisms that would not readily apply to residential customers, such as a variable cost of power, a seasonal payment reserve, or service guarantees may help reduce payment risks.

8.3 Knowledge and Skills

Many rural microenterprises lack the technical knowledge and skills needed to run a business (EUEI- and GIZ 2013).

There is no easy solution to this challenge, and it often requires sustained engagement over a long period of time. One potential solution is providing local business and financial mentoring. E4I is doing this in support of entrepreneurs though a process it has developed over many years of providing related support. Appendix A provides some details of the E4I process and could serve as a guideline or starting point for others looking to develop similar efforts or support programs.

8.4 Social Acceptance Risk

Another challenge for micro-grid operators is social acceptance by the local community. If an operator is not transparent about its plans and does not consider local public opinion, the risk of the rural electrification development failing is high (Manetsgruber et al. 2015).

These risks can be partially mitigated by engaging early with the community and running community awareness campaigns. The engagement process should typically include a kick-off meeting, training on electricity usage and business matters, awareness raising about the potential impact of productive appliances, and training on the installation and operation of those appliances. Micro-grid operators must also be sensitive to the displacement of existing local businesses created by enabling PU particularly if the new PU business owner is from outside the local community.

8.5 Technical Risk

Technical challenges and risks for micro-grid developers were discussed extensively in Sections 4 and 5. These risks can be mitigated through appropriate systems design and analysis of PU loads. Depending on the risk a variety of mitigation strategies can be used, and it is essential that both the developer and the entrepreneur understand the level of service that the micro-grid will provide.

9 Conclusions

The PUE in micro-grids holds great promise to both local economic development in rural areas of Africa and the financial viability of micro-grids. Successfully designing, developing, and operating businesses in rural Africa can be difficult. This report illustrates some of the challenges and opportunities for local entrepreneurs in a few key industries. The report is a resource that entrepreneurs, governments, and non-governmental organizations can use to help design programs, policies, and incentives to encourage economic development in these areas. Additionally, developers, engineers, and organizations studying and designing micro-grids can use this information to inform their technical and business decisions resulting in better understanding, faster uptake, and increased success with adding PU loads to both new and existing micro-grids.

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Appendix A: Energy 4 Impact's Productive Use Support Process

E4I has developed its own unique and holistic process for providing PUE support to microbusinesses and micro-grid project developers. It is based on 10 years of field experience incubating microenterprises in East Africa and Senegal. It has four pillars (Figure A1-1 and Table A1-1).

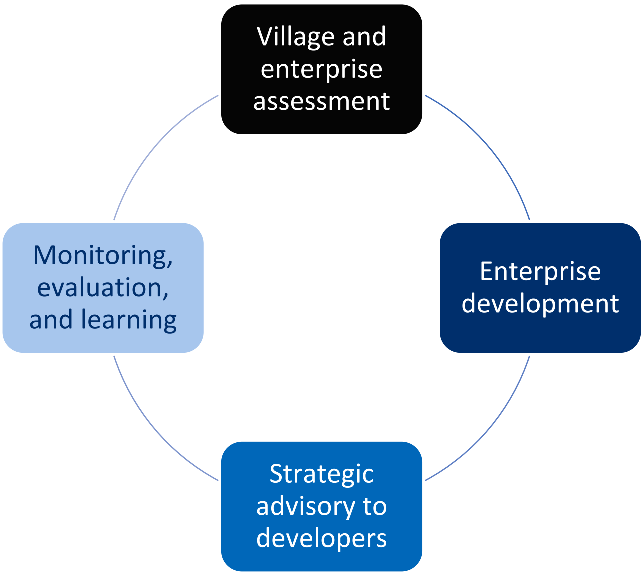


Figure A1-1. Four pillars of E4I process for providing PUE support (Source: E4I)

Table A1-1. Four Pillars of E4I Process for Providing PUE Support

PILLAR	DESCRIPTION
Pillar 1	**Village Assessment**—assessing the village economics (macroeconomics, demographics, and agriculture/primary industries) This step identifies the potential of new productive end-use activities that might be possible, once power is available. As per E4I experience, microbusinesses engaged in trading activities consume the least power, whereas businesses involved in light manufacturing and agriculture processing consume the most power at the village level. **Enterprise Assessment—**assessing microentrepreneurs who are interested in getting support and have interest and capacity to expand their businesses following the new connection This results in a short-list of local businesses that can scale-up their business thanks to access to electricity and viable productive investment.
Pillar 2	**Enterprise Development—**comprising: *Enterprise Engagement*—includes a kick-off meeting, training on electricity usage and business matters, and raising awareness on the potential impact of productive appliances *Business Mentoring and Technical Capacity Building*—providing in field customized business mentoring to microentrepreneurs focusing on: business case analysis of PUE, electricity usage, and business practices with the aim to sustainably generate higher incomes We help establish PUE equipment supply chains (i.e., identify PUE appliances, suppliers, prices, and power ratings). This facilitates more efficient uptake and creation of demand stimulation for PUE. We also help PUE enterprises establish themselves in their supply chains, identifying as applicable sources of raw materials, feedstock, and products for resale; and helping identify new marketing approaches and routes to market for these products/services. *Access to Finance*—reaching out to financial institutions to enable access to finance for microentrepreneurs so they can invest in electrical equipment to expand and/or launch their business idea This is a key barrier to accessing electrical appliances and has proved repeatedly to be an obstacle in day-to-day operations.
Pillar 3	**Advisory to Project Developers—**strategic advising, including: • Development of PUE strategy • Mapping of priority PU sectors • Establishment of microbusiness models for PUs • Setting of tariffs to encourage efficient electricity use • Technical system design, sizing, and configuration • Cataloging of efficient appliances • Development of partnerships with appliance suppliers • Management of supply chain • Asset financing • Assessment and forecast of electricity demand • Management of load • Assessment of willingness and ability to pay of end users • Bespoke demand stimulation tools.
Pillar 4	**Monitoring, Evaluation, and Learning—**collecting baseline and monthly monitoring data for several indicators to assess the impact on income and electricity consumption over time These indicators may include the number of beneficiaries served, business revenues, job creation, capital and running costs, electricity consumed, carbon emissions saved, debt service performance. Combined with qualitative feedback from the entrepreneurs and E4I mentors, the monitoring data are used to learn lessons and fine tune the interventions.

In conjunction with the previous description, E4I created a three-phase approach to implementing promotion activities:

- **Phase 1. Mobilization:** This phase is about mobilizing resources and planning for the launch of the Market Preparation phase. It is important at this stage to understand the current development status of the community and to identify and recruit local PUE champions. It is also important to ensure effective coordination with all project stakeholders, including the developer, the local entrepreneurs and community, and possibly the rural electrification authority or some other public institution.
- **Phase 2. Market Preparation:** This phase is about creating awareness about the income generation and job creation potential of PUE activities and informing the community about the potential in various value chains. For solar micro-grids, we are talking mainly about agricultural processing, food processing, light manufacturing, retailing, energy-powered services, and other such activities).
- **Phase 3. Market Engagement:** This phase is about implementation, including business training and mentoring, providing access to finance, market linkages for the entrepreneurs, technology and appliance training, and workplace health and safety.

Appendix B: System LCOE Modeling Data and Assumptions

For the LCOE and load profile tools, see Li (2018). Detailed LCOE tool information for the scenario analyzed in this report is provided in Table A2-1.

Table A2-1. LCOE Modeling Inputs and Assumptions

INPUTS	BASE CASE	COMPARISON
Geographical region	Lodwar, Kenya	Lodwar, Kenya
Load profile	Residential-heavy	Business-heavy
Percent of load served	95%	95%
Discount rate	10%	10%
PV/Battery Costs	Medium	Medium
Diesel Generator Costs	Medium	Medium
Diesel Fuel Price	$3.60	$3.60
Total distribution system costs	Default	Default
Pre-operating soft costs ($/kW)	Default	Default
Annual labor costs	Default	Default
Annual land lease costs	Default	Default
Assumptions		
Length of analysis	20 years	20 years
Average solar resource (global horizontal irradiance)	6.1 kWh/m^2/day	6.1 kWh/m^2/day
Installed PV cost	$1,800/kW	$1,800/kW
PV O&M	$36/kW	$36/kW
Useful life	20 years	20 years
Battery storage cost	$400/kW	$400/kW
Battery useful life	7 years	7 years
Inverter and balance-of-system costs	$900/kW	$900/kW
Inverter replacement cost	$450/kW	$450/kW
Battery O&M	$25 kWh-installed	$25 kWh-installed
Inverter useful life	10 years	10 years
Diesel genset cost	$400/kW	$400/kW
Useful life	10 years	10 years
Fuel consumption rate	10 kWh/gal	10 kWh/gal
Fuel cost	$3.60 gallon	$3.60 gallon
Fuel escalation rate	3%	3%
Total distribution system costs	$20,000	$20,000
Pre-operating soft costs	$1,200 kW	$1,200 kW
Annual labor costs	$3,000/year	$3,000/year
Annual land lease costs ($/year)	$800	$800

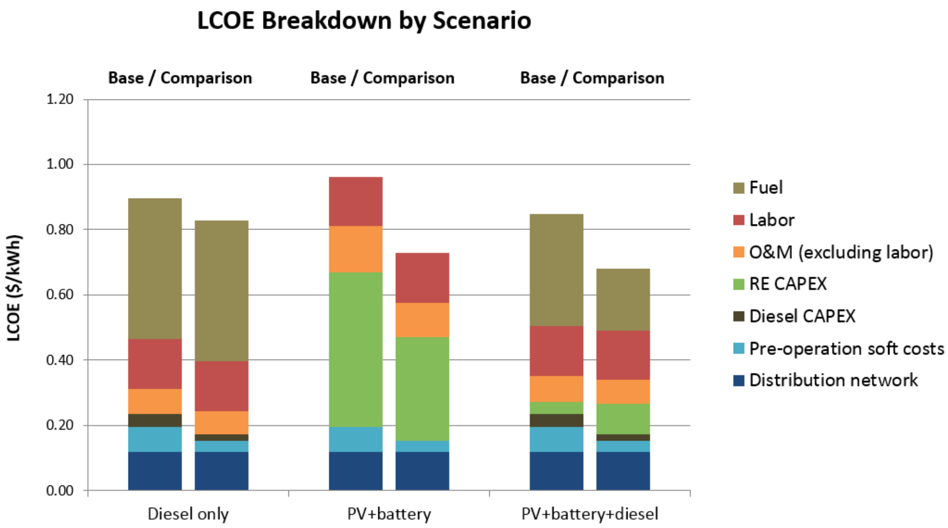
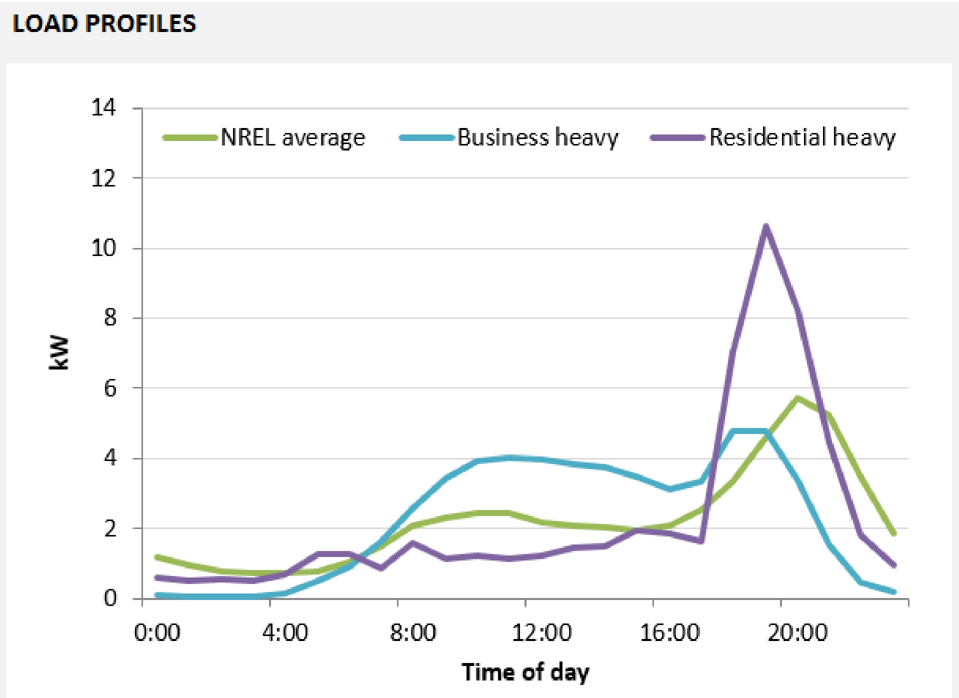


Figure A2-1. LCOE breakdown by scenario



Load Profile	Peak load	Annual Consumption
NREL average	5.71 kW	19,711 kWh
Business heavy	4.76 kW	19,711 kWh
Residential heavy	10.62 kW	19,711 kWh

Figure A2-2. Load profiles used in LCOE analysis

Only one day is shown because simulated loads do not vary across days.

Appendix C: Detailed Level of Service, Performance Monitoring, and Metrics Information

Power Quality

Electricity quality is typically measured in terms of voltage and frequency variations. The key question for PU customers is whether the power provided is of a sufficient quality to safely and effectively meet their needs. Most PU appliances cannot be operated properly if the voltage deviates from their design parameters. In addition, transformers draw a higher current at low voltage, subjecting the system to greater thermal losses and increasing the risk of burnout and fire. Low voltage usually results either from overload in the micro-grid or from long-distance, low-voltage cables connecting distant households to the grid. PU appliances, particularly motors, can drive down the voltage and disrupt supply to other customers within the same feeder. Frequent monitoring of the system voltages and frequencies as well as testing transformers should make it easier to investigate and solve issues with power quality. The QAF metrics for power quality are summarized in Table A3-1these metrics can form the basis of a discussion/analysis of the power provided by the micro-grid and the power quality requirements of the PU to determine if and how service can be provided.

Table A3-1. QAF Metrics and Service Levels for Power Quality

ISSUE	BASE LEVEL OF SERVICE	STANDARD LEVEL OF SERVICE	HIGH LEVEL OF SERVICE
AC Power Quality Phenomena			
Voltage imbalance	<10%	<5%	<2%
Transients	No protection	Surge protection	Surge protection
Short voltage-duration variations	<5/day	<1/day	<1/week
Long voltage-duration variations	<10/day	<5/day	<1/day
Frequency variations	48 Hz<f<52 Hz	49 Hz<f<51 Hz	49.5 Hz<f<50.5 Hz
DC Power Quality Phenomena			
Resistive voltage drop	<10%	<5%	<2%
Percent ripple	50% peak to peak (pk-pk)	20% pk-pk	10% pk-pk
DC ripple and switching noise	Unfiltered	Transient noise minimized	Ripple noise also minimized
Transients	No protection	Surge protection	Surge protection
Faults allowed per day	<5/day	<2/day	<1/day

Power Availability

Availability is defined as the amount of time a micro-grid can produce electricity over a certain period divided by the amount of the time in the period. The key question for PU customers is whether power is provided in the amount that meets their expectations and is available for the specified duration.

The QAF defines power availability levels that mirror the multitier framework defined by the World Bank (Bhatia and Angelou 2015) but defines them separately, giving system designers and operators the flexibility to specify the amount of energy consumers can expect. As in the multitier framework, power availability is defined by three parameters: power draw, energy availability, and duration of daily service.

PUE loads generally positively impact the availability of micro-grids. Depending on the service limitations of the micro-grid technology, some developers have tried to incentivize PU businesses to operate in non-business hours through “time-of-day” tariffs and other methods.

Tables A3-2–A3-4 summarize QAF metrics for power availability and peak level in terms of W and kWh. They can form the basis of a discussion/analysis of the power provided by the micro-grid and the power availability and level requirements of the PU to determine if and how service can be provided.

Table A3-2. QAF Metrics and Service Levels for Duration of Daily Service

DAILY SERVICE AVAILABILITY LEVEL	POWER AVAILABILITY
Level 1	No guarantee of availability
Level 2	Variable certainty: *x* hours a day with *y* certainty
Level 3	Full certainty: planned continual availability

Table A3-3. QAF Metrics and Service Levels for Peak Power Levels

POWER LEVEL	PEAK LEVEL (W)
Level 1	>3
Level 2	>50
Level 3	>200
Level 4	>800
Level 5	>2,000
Level 6	>5,000

Table A3-4. QAF Metrics and Service Levels for Energy Use per Service Level

ENERGY LEVEL	PEAK LEVEL (KWH/YEAR)
Level 1	>4.38
Level 2	>73
Level 3	>365
Level 4	>1,250
Level 5	>3,000
Level 6	>73,000

Reliability

A key issue for PU customers is whether electricity is supplied with enough reliability to meet their demand needs. The reliability of micro-grids in sub-Saharan Africa is generally much better than that of national grids in sub-Saharan Africa.

Blackouts can significantly disrupt productive activities, leading to financial losses, the extent of which depends on the frequency and duration of the interruption. Some PUs use costly backup generators to address this issue.

Table A3-5 summarizes QAF metrics for power reliability and can form the basis of a discussion/analysis of the power provided by the micro-grid and the power reliability requirements of the PU to determine if and how service can be provided.

Table A3-5. QAF Service Levels and Metrics for Power Reliability

ISSUE	BASE LEVEL OF SERVICE	STANDARD LEVEL OF SERVICE	HIGH LEVEL OF SERVICE
Unplanned $SAIFI_{XX}$[a]	<52 per year	<12 per year	<2 per year
Unplanned $SAIDI_{XX}$[a]	<876 hours (90.00% reliability)	<438 hours (95.00% reliability)	<1.5 hours (99.99% reliability)
Planned $SAIFI_{XX}$[a]	No requirement but should be defined	No requirement but should be defined	<2 per year
Planned- $SAIDI_{XX}$[a]	No requirement but should be defined	No requirement but should be defined	<30 minutes (100% reliability)

[a] SAIFI and SAIDI are typically assumed for power systems that are specified to provide full-time 24-hours/day energy service. A subscript is used in the QAF for systems that provide partial hours/day service, as the number of planned and unplanned interruptions and length of any interruptions should be normalized by the percentage of hours of service.

Appendix D: Additional Details of Milling and Water Treatment Analysis

The tables in this appendix provide additional details on the financial impact analysis related to milling from Section 7.1 and data inputs for modeling water systems from Section 6.5.

REopt Modeling

Table A4-1. REopt Modeling Assumptions

PARAMETER	VALUE
Location	Tanzania
Analysis period	20 years
Discount rate	15%
Installed PV costs	$1,800/kW
PV O&M	$36/kW/year
Storage costs	$400/kWh
Inverter/balance of system costs	$900/kW
Storage O&M	$25/kWh-installed/year
Generator costs	$400/kW
Generator O&M (fixed)	$25/kW/year
Generator O&M (variable)	$0.023/kWh
Fuel cost	$3.20/gal
Annual fuel escalation rate	3%
Total distribution system costs	$20,000
Pre-operating soft costs	$1,200/kW
Annual labor costs	$3,000/year
Annual land lease costs	$800/year

Table A4-2. Load Characteristics Modeled

LOAD CHARACTERISTICS	PEAK KW	ANNUAL KWH
Original load	5.71	19,711
10-kW mill, 33% loading 8 hours/day	12.42	26,601
2.5-kW mill, 33% loading 8 hours/day	5.71	21,433
10-kW mill, 50% loading 8 hours/day	12.42	30,111
10-kW mill, 16.5% loading 8 hours/day	12.42	23,156
10-kW mill, 33% loading 8 hours/day (November–April)	12.42	22,573
10-kW mill, 33% loading 8 hours/day (December–February)	12.42	21,380
10-kW mill, 50% loading November–April, otherwise 15% loading	12.42	26,045

Water Treatment System

Table A4-3. Key Data Inputs for Water Treatment Modeling

LOCAL WATER DEMAND	
Number of households in village	200
Average household water use per day	12 L
Average residential use per day	2,400 L
Commercial/government water use per day (assuming one of each below)	
Restaurant	80 L/day
Bar	40 L/day
Health clinic	40 L/day
School	80 L/day
Total Commercial Use Per Average Day	**240 L**
Total Water Demand Per Day	**2,640 L**
Estimated weekly production	18,480 L
WATER TREATMENT EQUIPMENT	
Plant Capital Costs	
Ultra-filtration water treatment system	$10,500
Ocean Freight	$800
Additional infrastructure costs for tanks, pumps, etc.	$2,000
Building to house system and shop	$2,000
Installation costs	$2,800
Customs/duties	$1,500
Total Installed Cost	**$19,600**
Plant production capacity per hour	1,800 L
Store operating hours per day	10
Plant operating hours per day	2
Plant power demand when connected to AC micro-grid	90–240 V AC 50/60 Hz, 400 W
Additional shop power demand	25 W
Other power supply: (Use one of the following in addition if city power is not reliable)	
Generator	90–240 V AC 50/60 Hz 1,000 W
Batteries 948-V array	12 V 100 AH batteries
Solar panels	(48–300 V DC) 500–1,000 W
Available power vs. production rate when connected directly to solar panels	
50 W	300 L/hour
100 W	600 L/hour
200 W	1,200 L/hour
>200 W	1,320 L/hour

Plant electricity use per hour of operation	0.4 kWh
Shop energy use per hour	0.025
Plant electricity use per year	383 kWh
Cost of micro-grid power	0.90/kWh
Plant electricity costs per year	**$344.93**
Plant Operating Costs (Excluding Electricity)	$/Liter cost (assuming 20,000 liters per week)
Operator(s), paid weekly + commission	0.013024481
Raw water, per liter (if applicable)	$0.00163
Repair pump	$0.00014
Replace pump	$0.00017
Replace UF membrane	$0.00032
Replace activated carbon	$0.00007
Replace polishing filter	$0.00008
Other repair/replacement/technician	$0.00035
1 liter of 5% chlorine	$0.000039
1 liter of 5% ammonia	$0.0000044
Bottle caps and seals (optional)	0.000695
Total Annual Operating Cost Per Liter	**$0.01652**
Maintenance Costs	**$0.00117**
Total/Day	**$47.20**
Plant Revenues	
Water price	$0.06/L–0.14/L
Water price	$0.06
Annual revenue from water sales	$57,658
Annual costs for operations	$17,573
Annual profit	$40,085
Simple payback	4 months

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