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SOLAR MILLING: EXPLORING MARKET REQUIREMENTS TO CLOSE THE COMMERCIAL VIABILITY GAP

JANUARY 2020

EFFICIENCY FOR ACCESS COALITION

This report was developed by Energy for Impact (E4I) and the Efficiency for Access Coalition Co-Secretariat, CLASP.

Efficiency for Access is a global coalition promoting energy efficiency as a potent catalyst in clean energy access efforts. Since its founding in 2015, Efficiency for Access has grown from a year-long call to action and collaborative effort by Global LEAPand Sustainable Energy for All to a coalition of 15 donor organizations. Coalitionprogrammesaim to scale up markets and reduce prices for super-efficient, off-and weak-grid appropriate products, support technological innovation, and improve sector coordination. Current Efficiency for Access Coalition members lead 12programmesand initiatives spanning three continents, 44 countries, and 22 key technologies.

CLASP is a non-profit organization which is an epicentre of ambitious and collaborative efforts to prevent catastrophic climate change and make the world sustainable for all. CLASP works together with policymakers, governments, technical experts, industry and others in the supply chain, donor organizations, consumers and consumer groups, and other stakeholders to develop and lead markets towards the highest-quality, lowest resource-intensive products. CLASP envisions a world in which appliances and other products are life-changing, low-impact, and environmentally responsible.

Energy 4 Impact is a UK-registered non-profit organization that seeks to reduce poverty through accelerated access to energy, providing technical, commercial and financing advice to off-grid energy businesses in Sub Saharan Africa (SSA), including over 100 mini-grid developers. The NGO's efforts have supported the growth of 4,700 businesses, resulting in 17 million people gaining better access to energy, 10,000 jobs, and 12.8 million tonnes of CO_2 being abated. The capital raised by those businesses with our support has amounted to $135 million.

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ACRONYMS & ABBREVIATIONS

AC	Alternating Current
AES	Additional Energy Services
CAPEX	Capital Expenditures
CBO	Community Based Organization
DC	Direct Current
E4I	Energy for Impact
hp	Hoursepower
hr.	Hour
KES	Kenya Shillings
kW	Kilowatt
kWh	Kilowatt Hour
LCC	Life Cycle Cost
MFI	Microfinance Institution
O&M	Operations and Maintenance
OPEX	Operational Expenditure
PU	Productive Use
PV	Photovoltaic
RMS	Remote Monitoring System
SACCO	Savings and Credit Cooperative
SSA	Sub-Saharan Africa
TZS	Tanzania Shilling
UGX	Uganda Shilling
USD	US Dollar
W	Watt
Wh	Watt Hour

FOREWORD

Solar milling is a complex process – from a technology, market fit and business case perspective. For example, solar milling does not have the value addition potential that solar water pumps provide to high value food crops, as milling deals with the lowest value food crops where the profit margins are minuscule. Milling also does not represent a big household spend like charcoal or kerosene expenditures, which stove and solar home system (SHS) companies have to work with – instead, households using diesel hammer mills spend around $50/year for milling. Additionally, milling requirements, preferences and demand vary geographically and seasonally, making the techno-economic case particularly challenging.

However, milling has arguably the potential to become the most important productive use (PU) technology, not only because of the universal need that off-grid communities have for milling services, but also because it is a uniquely gender-segregated household task –women or girls are always the ones tasked with food processing. In Africa, about 40 billion hours of off-grid women's unpaid time are spent on processing each year. Automating this process would free up a significant amount of time for women and girls, which could be put towards other productive or educational activities, and support women's empowerment.

Within the industry the importance of solar agro-processing is being increasingly recognised for its potential to catalyse energy access. The Efficiency for Access Coalition, IFC's new PULSE program, and USAID's successor to Powering Agriculture all prioritise agro-processing as one of the top three most important technologies to realise change.

The solution required is not simply a matter of transitioning repurposed products into market, nor is it about replacing diesel mills with a solar equivalent. These realities set solar milling apart from practically every other solar powered product and appliance that has been brought to market. Solar milling is complicated on many fronts and requires new innovation across multiple engineering disciplines and business models.

Agsol will not be deterred from this challenge and neither should the industry. The complexity of solar milling is high, but the opportunity and need for accessible and better milling services is clear. Efficient, affordable, solar milling technologies will be an essential piece of the puzzle in catalysing higher tier energy access and they have the potential to be one of the greatest liberators of off-grid women's time.

Matt Carr – CEO Agsol

AGSOL

EXECUTIVE SUMMARY

For the majority of communities in sub-Saharan Africa (SSA) that rely on grains and cassava for their main staple food crop, milling is a crucial processing activity. In rural off-grid communities, diesel powered mills are commonly used to displace the need for manual grinding and pounding. Diesel mills have relatively low capital costs and a well-developed supply chain for repair and maintenance. However, diesel mills have high operational costs, are difficult to operate, are less reliable than electric mills, run on engines that pollute the environment[1], and are not always placed close to their intended users. This increasing the time and labour burden for women and children, who are often tasked with food processing.

Electric mills equipped with either alternating current (AC) or direct current (DC)/Brushless DC (BLDC) motors powered by mini-grids or stand-alone solar photovoltaic (PV) systems offer an alternative to diesel mills. Electric mills are reliable, easy and cheap to operate, environmentally friendly and properly sized to allow more distributed placement, reducing the time and labour burden associated with accessing milling services.

A significant body of work is underway to understand the viability of grain milling on mini-grids.[2,4,4] However, the stand- alone PV system case (characterized as solar milling, in this report) is less explored. There are only a few companies deploying these technologies. Solar milling companies must be able to match mill throughput to user demand, sizing thier mills to maximise utilization and improve energy efficiency to reduce capital costs, all whilst competing with oversized diesel mill incumbents. Pilot tests of innovative technologies provide market-based learnings. This information is essential for charting the direction for solar mill manufacturers, distributors, investors, and other actors around this technology.

Methodology

The project team undertook an initial literature review and market scoping—including stakeholder consultation. Next, the team undertook functional laboratory testing of the Agsol Gen2 mill to understand and iterate on the existing technology prior to field testing. Ten mills were deployed to in-country partners and four installed during the pilot in the field. Further, both solar mill users (2) and potential users (24) were interviewed to understand the market needs, user behavior and preferences, and technical and commercial product viability. This study uses a market-led approach to assess the viability of solar milling. It identifies research areas to explore based on assumed risk factors in the market, namely: technology, market, supply chain, business models, and financing and additional energy services.

Milling Technology

The focus of this study is maize milling in East Africa. Maize is the most commonly produced cereal in the region, accounting for 75% of the continent's total annual harvest of 64 million tonnes (2015).[5] Table 1 summarizes currently available options for small scale maize milling.

Solar mills can be configured with batteries (battery-coupled) or without (direct-drive). Table 2 shows the main differences in the two configurations. The choice of the grinding mechanism is typically dictated by preference in the fineness of the final product. For example, hammer mills produce finer flour and are more common in East Africa, where fine flour is generally preferred whilst plate mills, which give more texture to the final product are mostly used in West Africa and the Sudan, where people prefer coarser, whole grain flour .

The choice of the grinding mechanism is typically dictated by preference in the fineness of the final product. For example, hammer mills produce finer flour and are more common in East Africa, where fine flour is generally preferred.[6] Plate mills, which give more texture to the final product, are used mostly in West Africa and the Sudan, where people prefer coarser, whole grain flour.[7]

Functional tests on the Agsol G2 mill show potential for brushless DC (BLDC) motors to product gains in energy efficiency. However, more research is needed to uncover the best available technology and optimum motor-controller combinations to maximise the benefits of these motors for off-grid appliances.

1. IFC. The Dirty Footprint of the Broken Grid Report. 2019.
2. E4I , NREL. Productive Use of Energy in African Micro-Grids: Technical and Business Considerations. 2018.
3. GMG Facility. Milling as a Productive Application in Green Mini-Grid (GMG) Systems (Practitioner's Guide). 2018.
4. DelCore, A. Income Generating Appliances Study. 2018
5. Rose, M. Mapping of Cereals, Fisheries and other Productive-use Businesses for Village Mini-grids. E4I. 2019.
6. Clarke, B., Rottger, A. Food and Agriculture Organization of the United Nations. 2006. http://www.fao.org/3/j8482e/j8482e.pdf
7. Clarke, B., Rottger, A. 2006.

Table 1: Comparison of available option for maize milling in East Africa

Category	Diesel mill	Electric Mill	Retrofit Mill	Solar Mill
Details	Driven by a diesel-powered engine which is coupled to the mill.	Driven by an AC induction motor coupled to the mill via a belt	The existing mill's diesel engine is replaced with an electric motor	Driven by a solar PV system powered AC or DC motor
Availability	Most common in areas without electricity	Most common in electrified areas, also used on mini grids	Not common. It is being piloted by JUMEME[8] on their mini grids in Tanzania[9]	Not well developed
Power Rating (kW)	7.5 – 17.5 kW	7.5 – 15 kW	7.5 – 15 kW	1.5 – 2.2 kW
Estimated Cost (USD)	1,000	2,000	500[10]	2,500[11]
Average Throughput (kg/hr.)	120-150[12]	120 - 150	Currently not available	32[13]

Table 2: Comparison of battery-coupled and direct-drive solar mills

Category	Battery-coupled solar mill	Direct-drive solar mill
Cost	Batteries are expensive components for off-grid PV systems. The G2 mill retailed for USD 2,500 while a direct-drive mill was quoted at half the price.[14]	No battery used so capital costs are lower, replacement costs for batteries are not considered.
Additional Services	Offers opportunity for connecting other appliances to the battery which can potentially increase mill owner revenue.	The electricity generation asset is dedicated to milling only.
Operational Hours	Milling can be done at any time of day so long as there is adequate energy capacity stored in the battery bank.	Milling only occurs during peak sunshine hours.
Continuous Operation	Milling is not disrupted by low irradiance (can occur during cloudy conditions)	Milling may cease when irradiance is below required running requirements.

Results

The literature review and stakeholder interviews covered potential markets for off-grid milling, milling technologies, regulations around milling, sources of finance, and viable business models in off-grid areas of Eastern Africa. Agsol carried out a functional test that coupled the hammer mill to five different electric motors following a methodology adapted from Colorado State University (CSU) laboratory testing protocol supplied by Factor[e] Ventures.[15] Finally, the study was designed to commercially deploy ten solar mills in Tanzania, Kenya, and Uganda through in-country partners. During the study period, in-country partners deployed four mills for three months each. Two mills were established in Kenya on a Pay-As-You-Go (PAYG) plan offered by Mwezi Solar. Two mills were placed in Uganda as demonstration sites under a United Nations Capital Development Fund (UNCDF) programme.[16] The study also includes interviews with diesel mill owners who expressed interest but did not acquire solar mills, to provide a more in-depth understanding of market preferences. In total, 45 respondents were interviewed across various categories see Table 3.

The sample of this study is small and is not intended to be, representative of the entire respondent category. The results of this study should only be used as directional indicators of the market requirements in sampled regions in East Africa (see Annex 1) and should not be generalised for the entire region.

Technology

In comparison to diesel mills, battery-coupled solar mills, as with other electric mills, have higher health and safety standards, offer continuous run times without unsafe modification and constitute a user-friendly design that allows women and persons living with a disability to operate the mill and perform essential operation and maintenance activities. However, the solar mill throughput, approximately 32.7kgs/hr, remains too low to meet peak customer demand, leading to intolerable wait times, double what customers prefer.

8. JUMEME is a mini-grid developer in Tanzania.
9.E4I , NREL. 2018.
10. Considering only the motor costs.
11. Cost includes PV system batteries and other balance of system (BOS) components.
12.E4I , NREL. 2018.
13. Based on results from the functional tests conducted by Agsol.
14. This may not be accurate as there were subsidies in the retail offer.
15 FACTOR[e] is a venture development firm which supports entrepreneurs through risk capital and technical resources. (http://www.factore.com/)
16. UNCDF funded demos in Uganda. PowerTrust supplied 2 mills for three months..

Table 3: Respondents interviewed during the study

Interviewed group	Details	Description	Responses
Mill Manufacturers	Agsol	Manufactured the mills used in this study.	1
In-Country Partners	Simusolar[17] in Tanzania, Mwezi[18] in Kenya and PowerTrust[19] in Uganda	Potential distributors of off-grid milling machines. Criteria for selection: • Have experience in the off-grid solar space with an interest in distribution of off-grid appliances. • Have requisite experience in last mile distribution of off-grid appliances particularly for productive use. • Have technical capacity, resources and experience to provide marketing, customer acquisition, after sale services and maintenance.	3
Solar Mill Owners	In Uganda and Kenya	Milling only occurs during peak sunshine hours.	2
Diesel Mill Owners	In Uganda, Kenya, and Tanzania	Diesel mill owners who initially expressed interest in solar mills but did not purchase one over the duration of this study.	15
Solar Mill Customers	In Uganda and Kenya	Customers who visited the piloted solar mills in Uganda and Kenya.	24
		Total number of respondents	**45**

A significant challenge for solar milling technology is right-sizing the energy system for cost-effectiveness and throughput whilst maintaining high utilisation to increase profitability. Best-in-class BLDC motors, mill design improvements and better motor controller compatibility could increase efficiency of the mills mitigating energy system costs. Maximising utilisation of solar mills directly translates to increased profits and a more commercially viable product. The report identifies two technology levers to increase utilisation: 1) use of battery-coupled mills, which are general preferred by potential millers (95%) despite the added capital cost and 2) design for multi-functionality. The ability to mill multiple grain types or add ancillary series increases mill profits, broadens market reach for a larger customer base, and presents a competitive edge to incumbent diesel mills.

Though solar mills are easy to operate, to be successful, they also have to be easy to repair, troubleshoot, and maintain. Potential mill owners will only attempt light touch repair. Third party maintenance and repair infrastructure, while much needed, will take time to build. Therefore, solar mill design must be robust and simple enough to service with easily available components. Designs may even with to be that are compatible with existing mills, e.g. use the same screens. The availability and interoperability of spares should be coupled with training for local technicians or mill owners on basic troubleshooting, repair and maintenance.

The ideal technology bundle for distributors is a solar milling kit comprising of milling components (mill, motor and controls) provided by the manufacturer and bundled with solar photovoltaic (PV) and balance of system,[20] which may be provided by the distribution partner (if they also stock solar PV). This bundled kit would be modular, allowing for expansion and integration of other appliances. A modular kit would increase the value proposition for the mill distributor and potential mill owners.

Supply Chain

This study also considers the downstream provision of products and services to clients (in-country partners and mill operators). This involves sourcing, manufacture, assembly and distribution of solar mills and their spares, as well as on-boarding activities such as training. Solar mills are usually a combination of imported components and locally produced and assembled components. Movement of goods across borders is challenging in many countries. More research is needed make easily available shipping and importation guidelines, as well as summaries of existing tax and duty exemptions for agricultural processing machinery.

Solar mill manufacturers could leverage established distribution channels in East Africa. Local distributors of off-grid energy products could serve as a primary distribution channel. Their branches and agenda have a broad reach in the region. Local distributors are also trusted in the market and can offer some level of technical support to end-users. These distributors mainly source new products from suppliers who can provide training and product support, such as warranties. Product support is crucial for potential solar mill operators, the majority of whom consider after-sale services a key driver for purchase.

17. https://www.simusolar.com/
18. https://mwezi.org/
19. https://www.powertrusteastafrica.com/
20. The balance of system (BOS) encompasses all components of a photovoltaic system other than the photovoltaic panels. This includes wiring, switches, a mounting system, one or many solar inverters, a battery bank and battery charger.

Financing

The capital cost of solar mills and the energy systems required to power them are prohibitively high compared with incumbent technology. Compared with the most commonly used diesel mill, the G2 mill would not be cost-competitive until year nine of ownership. Further, solar mills may require additional capital expenditure by the owner to set up secure premises that can support PV mounting. These high capital requirements are prohibitively expensive in off-grid areas where potential mill owners lack the financial infrastructure to access credit.

Of the different options that exist to raise capital funds for solar mills, current and potential mill owners overwhelmingly prefer payments in instalments, either through a pay-as-you-go (PAYG) model, loans or leasing. Raising the full cost of asset is virtually impossible. Even putting together the deposits required for instalment schemes, at the current mill cost, is a challenge for mill entrepreneurs. Customer credit through distributors or other financial services can address this clear financing gap. If distributors offer consumer credit, they will also need investment, debt facilities or other financing options to maintain working capital.

Business Models

The right downstream business model (for mill operators) is key to maximising the gains from solving technology, supply chain and financing challenges. At the most basic stage, milling as a service[21] or sale of flour are both possible, though flour sale is less popular due to concern over the quality of the original grains. Milling fees are low and set by the market without much fluctuation. Given the high capital cost, solar milling must maximise utilisation of the mill and any ancillary systems to increase revenues and profitability.

Two examples of business models that can maximise utilisation are:

1. Provision of additional energy services leveraging the battery system. This model is closely linked with the technology lever of the multi –functionality of solar mills.

2. Demand side management to ensure peak operation at peak sun-hours through aggregated milling. This model may require customer behaviour change and trust, which is difficult given existing mill competition. However, if mill owners can creatively solve the question of tampering, there are significant utilisation gains to be had. Field pilots will be crucial to allow potential owner to experience the mill and innovate around the technology.

Market

Though current and potential solar mill owners interviewed overwhelmingly prefer solar PV as an energy source compared with diesel (95%), they have expressed concern over the cost, lower throughput, effects of weather on milling operations and availability of spare parts and qualified technicians for repair and maintenance. Their primary considerations when purchasing any mill are throughput (35%), energy efficiency (19%), and cost (18%). Mill customers consider proximity (33%), fineness of flour produced (27%), and throughput (11%) as the primary factors when selecting where to mill.

The penetration of both diesel and electric mills in the villages surveyed reveal competition for milling services. Twenty-two out of 24 villages surveyed had two to four mills located within a 1 km radius of eachother. Mill operators must offer a competitive advantage to win over customers. The high penetration of mills in these areas would make it difficult for new businesses to flourish. Near-term customers for solar mills are likely: 1) off-grid diesel mill operators whose engines have reached the end of life and 2) institutions such as schools, hospitals and prisons that require large quantities of food. More research is needed to estimate the near term market whilst work is also underway to understand diesel engine replacement models.[22]

Though potential mill owners are willing to pay more for a solar mill, they insist on a throughput equivalent to diesel mills. This increase in throughput can be achieved by larger, more expensive BLDC motors. Longer run times that increase daily production volumes can also achive similar throughout, but this also requires robust, high quality equipment. Although efficiency gains could mitigate the cost of larger, higher-quality motors, a more holistic, multipronged intervention on technology, supply chains and business models is needed to significantly bring down costs.

There is a large potential for solar milling to take off in the East Africa. However, for the market to mature, mill manufacturers need to balance cost, throughput and efficiency to meet market needs. Other market actors also need to support the manufacturers' move towards the appropriate balance of cost and throughput using the supply chain and business model levers explored in this study.

21. Charging a fee to grind grain or other products to floor.
22. NREL, E4I. 2018.

Conclusions and Recommendations

Though stand-alone solar PV powered mills have market potential, they are not yet commercially viable or competetive with incumbent diesel mills. While the operational costs of solar mills are much lower than diesel mills, the capital cost of the mill and energy system remain a major barrier to market entry. Reducing costs by improving the energy efficiency of solar mills and educating consumers on thier value proposition may unlock higher demand.

To address the challenges of this technology, we propose the following next steps:

Donors, investors and financiers should provide more patient and risk-ready capital for research and development, field testing and pilots of solar mill prototypes. These investments can push the technology towards the right balance of cost, throughput, and efficiency.

Consumer financing mechanisms and incentives for early adopters will also be critical to increase affordability. Building programs that bring energy and agricultural actors together to develop holistic approaches to the development of productive use equipment can also accelerate discovery of appropriate technologies and business models.

Suppliers and manufacturers should undertake rigorous market research within field activities as part of the introduction of novel technologies like solar mills.

Distributors should undertake market awareness to discover untapped markets, and consider offering or enabling financing for end consumers. Manufacturers need more research and technology development to iterate design towards mills appropriate for market needs.

Lastly, policymakers should integrate agricultural equipment provision into national policies and clarify taxes and duty exception that exist for these equipment.

Background and Context

For the majority of communities in sub-Saharan Africa that rely on grains and cassava as their main staple food crop,[23] milling is a crucial processing activity.[24] In rural off-grid communities,[25] diesel-powered mills are commonly used to displace the need for manual grinding and pounding.[26] The advantages of diesel mills include relatively low capital costs and a well-developed supply chain for repair and maintenance. However, diesel mills have high operational costs, are difficult to operate, are unreliable, polluting to the environment,[27] are not always located near their intended users and require frequent sourcing, purchase and transport fuel which. Inconvenient milling locations increase the time and labour burden for women and children tasked with food processing. The need for diesel fuel produces high operation costs and reliability issues.

Electric mills offer a clean, reliable alternative to diesel mills. Electric mills can be equipped with either alternating current (AC) or direct current (DC)/Brushless DC (BLDC) motors. They can be powered by renewable mini-grids or stand-alone solar photovoltaic (PV) systems. Electric mills are a reliable technology that is easy and cheap to operate and environmentally friendly. They are properly sized to allow for more distributed placement, reducing the time women and children spend traveling to the mill and the need for the mill operator to purchase diesel fuel.

Some sub-Saharan African mini-grids power milling businesses. JUMEME,[28] a mini-grid developer in Tanzania, is piloting the refurbishment of diesel mills by replacing old diesel engines with electric AC motors. This reduces upfront capital costs. The upfront investment in electric motors is much lower (USD 500) than the full electric mill (USD 2,000), and the payback period is shorter.[29] Mills often require lower tariffs to remain profitable, which mini-grid operators should consider when attempting to attract and retain mill customers.

Stand-alone PV system-run mills (hereafter referred to as "solar mills") have not been extensively field-tested to assess their market viability. The few existing studies indicate that the available technology is inappropriate for the intended use case, and no current technologies can compete with incumbent technologies. As in other technology solutions, solar mills face the same challenge of effectively matching demand and supply to maximise utilisation and reduce operation costs. Developing modular and flexible energy supply systems that track demand has been suggested as a possible solution.

Sizing of solar mills is also affected by when customers like to mill, as many prefer similar times of the day. Mill operators, therefore, prefer to purchase larger mills to remain competitive with other mill operators in the market and perceive an economic disadvantage to operating for longer hours for the same quantity of output on a small solar mill. Developing a product that meets the balance of mill operators' needs and viability requires a deeper understanding of the market through on-the-ground solar mill testing. A pilot test of a new solar milling technology was therefore attempted to address some of these concerns.

The Efficiency for Assess Coalition identified the Agsol milling machine as a potentially viable technology and provided support to enable a pilot. Agsol, an agro-processing appliance manufacturer based in Kenya, developed a BLDC solar mill for pilot study sites in Tanzania, Kenya and Uganda. The pilot was designed to test the solar mill's market viability in terms of meeting demand, creating a profitable business and providing the requisite technology. Off-grid regions with high maize production were selected for the pilot. Selected distributors were identified to market the mills to customers. Results from field testing provide market-based learnings, which are essential for solar mill manufacturers, distributors, investors and other actors in decision making.

Objectives

This report provides findings from field testing of solar mills in Eastern Africa on:

1. **The market requirements for solar milling machines**
2. **The commercial viability of solar mills**
3. **Opportunities for improving solar milling technology**
4. **Recommendations sector stakeholders**

Methodology

Literature review and market scoping

Though few resources on solar mills exist, the publications listed in the references section provided useful information to establish this pilot project. Our literature review covered potential markets for off-grid milling, milling technologies, milling regulations, sources of finance and viable business models in off-grid areas of East Africa. Market scoping via stakeholder interviews identified potential regions of focus and market preferences for the field pilot study design. The scoping activity also filled gaps and validated findings from the literature review.

23. NREL, E4I. 2018.
24. NREL, E4I. 2018.
25. Rose, M. 2019.
26. NREL, E4I. 2018.
27. IFC. 2019.
28. http://www.jumeme.com/
29. NREL, E4I. 2018.

Functional tests

This study tested and deployed the Agsol G2 (2nd Generation), a hammer mill that can be driven by various electric motors through a pulley-belt coupling. This battery-coupled mill allows for milling at any time of day and the provision of energy to other appliances. The potential to power additional appliances may translate to additional income for milling businesses.

Agsol conducted functional tests that coupled the hammer mill to five different electric motors: 1.5kW and 2.2kW single-phase AC motors, 1.5kW and 2.2kW three-phase motors and a 1.2kW BLDC motor coupled to a motor controller. Tests on these configurations provided inputs for calculation of throughput, energy efficiency and noise levels. Testing was done using a methodology adapted from Colorado State University (CSU) laboratory testing protocol supplied by Factor[e] Ventures.[30] This methodology was designed to test AC and DC motors in a highly-controlled laboratory setting but was adapted to create a simplified test method appropriate for a controlled but non-laboratory testing. Performance results are provided in the overview of off-grid milling section of this report.

Pilot study

Successful income-generating activities are market-driven. It is, therefore, vital to identify and understand the market needs before rolling out products or services to communities.[31] The pilot and research methodology were designed to gather insights on market needs and identify suitable use cases and deployment models for the solar mills.

Respondents for this study included mill manufacturers, distributors of off-grid energy products, solar and diesel mill owners and milling customers. The sample used is not, and was not intended to be, representative of the entire respondent category.

Respondents felt that the use of solar in milling would reduce their costs of operating maize mills, i.e. diesel/operational and maintenance costs.

This pilot study was designed to commercially deploy ten solar mills in Tanzania, Kenya and Uganda through in-country partners. In-country partners identified potential solar mill customers in off-grid villages with high maize production, experienced in the milling business and located close to operational offices of the in-country partners. During the study period, in-country partners deployed four mills for three months each. Two mills were established in Kenya on a pay-as-you-go (PAYG) plan offered by Mwezi Solar, and two were located in Uganda as demonstration sites under a United Nations Capital Development Fund (UNCDF) demo.[35] The mills generated interest, especially after potential customers viewed the mills in operation at the demo sites or were shown a video shown a video by visiting teams. Initial reactions include the following:

- Respondents felt that the use of solar in milling would **reduce their costs of operating maize mills**, i.e. diesel/operational and maintenance costs.
- A solar mill was preferable to a diesel mill since it **did not emit smoke, had lower noise levels and was more comfortable to operate**, especially by women
- Interested buyers felt that the solar mill was too expensive – they all compared it to the existing diesel mill. The capital expenditure on a diesel mill is lower (USD 1,000) than the

Table 3: Respondents interviewed during the study

Interviewed group	Details	Description	No. of responses
Mill Manufacturers	Agsol	Manufactured the mills used in this study.	1
In-Country Partners	Simusolar[32] in Tanzania, Mwezi[33] in Kenya and PowerTrust[34] in Uganda	Potential distributors of off-grid milling machines. Criteria for selection: • Have experience in the off-grid solar space with an interest in distribution of off-grid appliances. • Have requisite experience in last mile distribution of off-grid appliances particularly for productive use. • Have technical capacity, resources and experience to provide marketing, customer acquisition, after sale services and maintenance.	3
Solar Mill Owners	In Uganda and Kenya	Milling only occurs during peak sunshine hours.	2
Diesel Mill Owners	In Uganda, Kenya, and Tanzania	Diesel mill owners who initially expressed interest in solar mills but did not purchase one over the duration of this study.	15
Solar Mill Customers	In Uganda and Kenya	Customers who visited the piloted solar mills in Uganda and Kenya.	24
		Total number of respondents	**45**

30. FACTOR[e] is a venture development firm which supports entrepreneurs through risk capital and technical resources. (http://www.factore.com/)
31. Energy 4 Impact 2019
32. https://www.simusolar.com/
33. https://mwezi.org/
34. https://www.powertrusteastafrica.com/
35. UNCDF funded demos in Uganda. PowerTrust supplied 2 mills for three months.

offered price for the solar mill (USD 2,500). With more information on the potential savings that solar has over diesel in running appliances, this initial reaction may have improved.

- Potential buyers also felt that the **solar mill throughput was low**. A solar mill was quoted to have an output of 32.7kg/hr, while existing diesel engines they own have an output of 120-150kg/hr. They felt that a solar mill could, therefore, not satisfy their customers and lead to longer waiting times.

We also decided to include interviews with diesel mill owners who expressed interest but did not acquire solar mills to provide a more in-depth understanding of market preferences.

Remote monitoring systems (RMS) were mounted on the solar mills to collect data on system runtime and energy consumption to determine the "in-the-field" efficiency and production rate. Distributors used RMS to monitor appliances given on credit to ascertain whether their customers generated enough business to meet their repayment obligations and to manage their PAYG customer accounts. The RMS[36] devices mounted on the mills were, however, affected by vibrations during milling, leading to insufficient technical data. Therefore, there is an opportunity for RMS developers to create devices that are resilient and specific to such applications.

Data Collection and Analysis

We conducted a data collection exercise between July and August 2019 using two methods:

- Face-to-face surveys with solar and diesel mill owners, using structured cloud-based questionnaires.[37]
- Interviews with the solar mill manufacturer and in-country partners, using semi-structured questions and open discussions.

In total, we interviewed 45 respondents across various categories. Data collection challenges included:

- Programmatic time constraints: Due to limited time, only one round of data collection was competed. In-country partners felt they did not get enough time to market and sell the mills.
- Customer experience: All interested solar mill customers interviewed were diesel mill operators – their milling experience thus influenced their responses.

Results Structure

To demonstrate a market-led approach to analyse the viability of solar milling, we identified research areas based on assumed risk factors in the market. Table 4 explores the risk categories and associated research areas covered under this report.

Table 4: Risks Investigated

Category	Description
Technology	**Risk associated with the functionality and readiness of the technology**
Market	**Risk associated with market relevance and uptake of the product.** Once the technology is proven, does it have a market? How big is this market? Do customers need and want this product, and are they willing and able to pay for the product? Does the product meet their needs? Who are the potential customer segments?
Supply Chain	**Risks associated with delivering the product to the market.** What local players in the supply chain have a key role in delivering the product to the market, and how does this then affect the business model(s)?
Business Models	**Risks associated with the economic viability and scalability of the milling business,** to foster profitability for the parties involved (manufacturers, distributors and operators).
Financial Models	**Risks associated with unit economics of product or service delivery**, cost product/service delivery to both the suppliers and the operators (e.g. loan repayment periods vs product life), and revenue per customer.
Additional Energy Services	**Risks associated with ancillary service offerings by suppliers,** and the subsequent effect on product use and revenues. Do added services increase product demand, and how significantly do they influence product sales?

36. Provided by a leading developer in the region, RMS devices are used primarily on solar home systems.
37. Questionnaires were developed and put on Android-based survey application, Kobo Toolbox, which relayed responses to cloud storage.

OVERVIEW OF OFF-GRID MILLING

Maize is the most commonly produced cereal in SSA, representing over 16% of the 200 million hectares of cultivated land. Production is even higher in East Africa, where maize accounts for 75% of the areas total annual harvest of 64 million tonnes (2015).[38] Off-grid smallholder farmers in the region produce most of the maize.

Local, small-scale mill operators produce an average of up to 300kg of flour per day.[39] They usually mill the whole grain without removing the outer shell or hulling. This process yields whole grain flour, which is preferred by a majority of rural households due to its low price and presumed high nutritional value. However, some consumers prefer refined flour as they consider it to be of better quality.[40] Mill customers from Uganda, for example, prefer refined flour[41] and only use whole grain flour to cook porridge for home and institutional use, such as in schools. Customers from Tanzania and Kenya mainly consume whole grain flour.

A summary of options we found in the market for small scale milling are provided in Table 5:

Figure 1: Maize value chain in Sub-Saharan Africa with target section highlighted

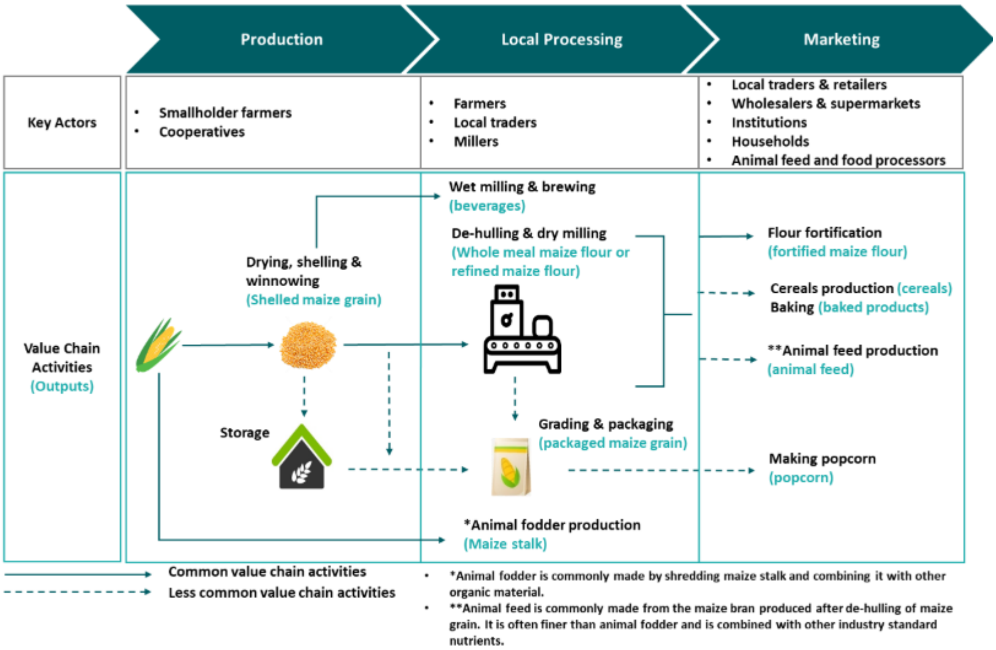


Table 5: Available milling options

Category	Diesel mill	Electric Mill	Retrofit Mill	Solar Mill
Details	Driven by a diesel-powered engine which is coupled to the mill.	Driven by an AC induction motor coupled to the mill via a belt	The existing mill's diesel engine is replaced with an electric motor	Driven by a solar PV system powered AC or DC motor
Availability	Most common in areas without electricity	Most common in electrified areas, also used on mini grids	Not common. It is being piloted by JUMEME[42] on their mini grids in Tanzania.[43]	Not well developed
Power Rating (kW)	7.5 – 17.5 kW	7.5 – 15 kW	7.5 – 15 kW	1.5 – 2.2 kW
Estimated Cost (USD)	1,000	2,000	500[44]	2,500
Average Throughput (kg/hr.)	120-150[45]	120 - 150	Currently not available	32[46]

38. Rose 2019
39. From E4I observation
40. They considered quality as the whiteness and fineness of the flour. This flour also cooks faster.
41. Refined flour is made from hulled maize grains.
42. JUMEME is a mini-grid developer in Tanzania.
43. NREL & E4I 2018.
44. Considering only the motor costs.
45. NREL & E4I. 2018.
46. Based on results from the functional tests conducted by Agsol.

Solar Mills

Stand-alone solar PV systems (usually consisting of PV panels, batteries and a charge controller) can power a grain mill. Batteries are optional, as mills can run off solar PV panels directly without batteries. Figures 2 and 3 show the layout of a battery-coupled mill and a direct-drive mill.

Battery-coupled energy systems can provision additional energy services outside milling hours, e.g. phone and battery charging. These services could provide alternative income-generating avenues for solar mill owners that may attract more customers, e.g. charging phones at a low cost or for free for milling customers. Additional revenue for the owner may reduce the system's payback period as well. The provision of additional energy services is, however, dependent on the availability of stored energy, and whether the energy system is sized to only meet the energy demand of the mill without additional capacity.

Direct-drive applications have been very successful in solar water pumping where variable speed inverters are used to vary the flow of water pumped with varying insolation. The application of these types of inverters for a solar mill would, however, be challenging, given that a mill's throughput (unlike water flow rate in water pumping) cannot be varied to match the energy available at a given instance. Low insolation may cause the mill to halt, as milling has a minimum energy threshold requirement. Battery-coupling, on the other hand, supports the reliable operation of a mill. Supply from batteries allows the spread of the milling process over an extended period by providing a steady operating voltage to the motor. Batteries also provide the capacity to mill at maximum throughput outside peak sun hours and at night.

Figure 2: Layout of a battery-coupled solar mill

Figure 3: Layout of a direct-drive solar mil[47]

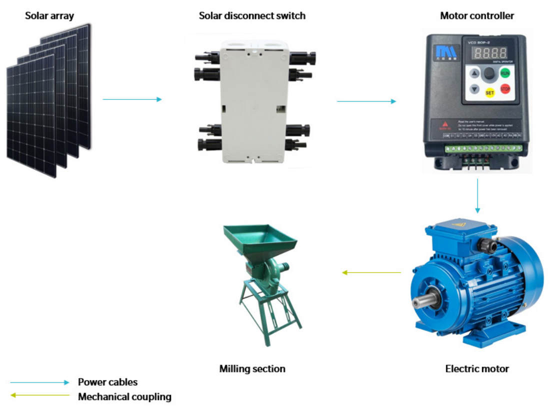


Table 6: Distinctions between direct-driven and battery-coupled solar mills

	Battery-coupled solar mill	Direct-drive solar mill
Cost	Batteries are expensive components for off-grid PV systems. The G2 mill retailed for USD 2,500 while a direct-drive mill was quoted at half the price.[48]	No battery used so capital costs are lower, replacement costs for batteries are not also considered.
Additional Services	Offers opportunity for connecting other appliances to the battery, which can potentially increase mill owner revenue.	The generation asset is dedicated to milling only.
Operational Hours	Milling can be done at any time of day so long as there is adequate energy capacity stored in the battery bank.	Milling only occurs during peak sunshine hours.
Continuous Operation	Milling is not disrupted by low irradiance (can occur during cloudy conditions)	Milling may cease when irradiance is below required running requirements.

47. These layouts are for informational purposes only. The order of equipment may change depending on level of control required. We are vendor agnostic and therefore used the equipment merely as examples.
48. This may not be accurate as there were subsidies in the retail offer.

Mill Selection

Hammer mills and plate mills are widely used by rural communities for dry milling due to their low capital, low maintenance costs and ability to process dry maize grain into fine flour.[49] Preferences in the desired fineness of final product typically determine the choice of mills used in a particular part of the world. Hammer mills produce fine flour, which is preferred in East Africa.[50] Plate mills are mostly used in West Africa and the Sudan, where people prefer coarser, whole grain flour, which gives more texture to the final product.[51] The fineness of the particles is further regulated using sieves of different mesh sizes.[52]

Results from Functional Testing

Table 7 gives a summary of the results from the functional tests on the G2 hammer mill coupled to different motors. We found the AC three-phase motors to be more energy-efficient compared to others tested. However, the application of three-phase motors on stand-alone PV systems is not feasible due to challenges in the cost-effectiveness of the energy system. A three-phase motor would need more robust equipment. Motor controllers and inverters have a high cost. Most of the available power equipment for standalone systems is in single-phase version.

BLDC motors are typically used in applications requiring high-efficiency and low-maintenance requirements, e.g. water pumping. From these tests, however, the BLDC motor did not stand out on its energy efficiency for two reasons:

- Use of an unbalanced motor-controller configuration, which reduced the efficiency of the drive.
- Use of a lower-grade BLDC motor compared to the best available technology AC motors used. This was mainly driven by lack of availability due to issues sourcing a high grade and mill-compatible BLDC motor.

These results, therefore, do not reflect an ideal comparison of motors to consider for solar mills. There is an opportunity for more research using highly-efficient BLDC motors and correct motor-controller combinations to fully exploit the benefits of these motors for off-grid appliances.

Table 7: Results from functional tests of different motors

	1-phase 1.5 kW	1-phase 2.2 kW	3-phase 1.5 kW	3-phase 2.2 kW	BLDC 1.2 kW
Energy intensity (Wh/kg)	40.3	101.1	20.3	33.2	43.58
Throughput (kg/hr)	32.7	53.9	23.2	40.4	31.97
Noise levels (dB)	77.4	77.2	77.8	77.8	77.4

49. Rose, M. 2019.
50. Clarke, B. 2006.
51. Clarke, B. 2006.
52. Ebunilo P. 2010.

The Technology

In considering the viability of solar milling technology, this report examined responses from current and potential solar mill owners as well as milling customers. Due to the nascence of the solar milling market, it is crucial to understand the potential value proposition in comparison with the most popular incumbent technology, diesel mills.

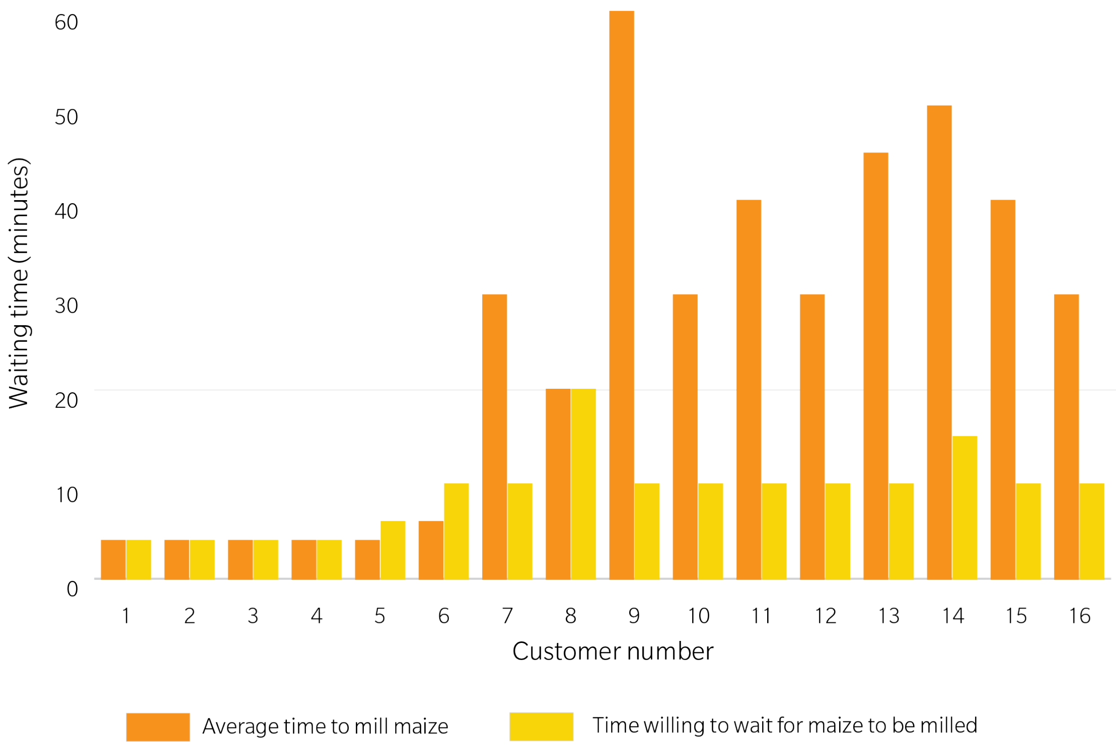
Operators and customers who interacted with the solar mill were not satisfied with its low throughput of approximately 32.7kgs/hr, primarily because of the associated increase in waiting times. For mill owners, throughput is a significant consideration when buying a mill. Low throughput increases wait times for customers seeking milling services, reducing customer satisfaction and potential income for the mill owners. Sixty-three percent of milling customers surveyed prefer to wait for a maximum of 10 minutes per visit. However, milling flour at a solar mill meant waiting 25 minutes to mill the same amount of flour. Use of a drop and pick model[53] would reduce milling waiting times and allow the mill owner to schedule milling appropriately. This model was not tested during the pilot, but interviews show 62% of customers surveyed are not willing to leave their grain and pick up their flour later due to fears of tampering or having their grains exchanged without oversight. The minimum solar mill throughput to meet the daily demand of 300 kg of flour in the surveyed locations would be of 60kg/hr assuming 5 hour of peak operation.

Equation 1: Throughput[54]

$$Throughput = \frac{Feed\ input\ in\ kg}{Milling\ time\ in\ hours}$$

A significant challenge for solar milling technology is right-sizing the energy system for cost-effectiveness, whilst maintaining high utilisation to increase profitability. Cost is an essential measure of comparing different sources of energy. Whilst the commercial viability of diesel mills is proven, and that of electric mills on mini-grids is being explored, stand-alone solar for milling has not yet become developed enough to meet the competitive costs of energy offered by the other two scenarios. For diesel and mini-grids, the cost of energy, for the miller, is directly proportional to utilisation,

Figure 4: Waiting times for solar mill customers



53. This involves leaving maize with a mill operator and picking flour later. The mill operator schedules when to mill – for solar mills this is when the energy cost is lowest i.e. during the day.
54. Olajide, O. 2016.

while in solar systems, it remains constant. This means that higher utilisation at a constant cost of energy would lead to higher milling profits sooner, if the system is right-sized for its use case. From our analysis, the cost of energy for diesel mills is USD 0.18/kWh. For the G2 solar mills, it was USD 1.9/kWh due to the high capital cost of the PV system, batteries and balance of system.

The cost of the energy system is also influenced by the efficiency of the motor or engine. **The efficiency of the pilot solar mill was significantly higher than that of diesel mills encountered in the field.** The average energy intensity of diesel mills encountered was 0.14kWh/kg, while that of the solar mill was 0.04kWh/kg. With more advances in the design of BLDC motors used in solar mills, their efficiency could increase further, reducing the capital costs in the process. These improvements include the use of best-in-class motors, mill design improvements and motor-controller compatibility. Use of highly-efficient components and right sizing the energy system to fit the use case is a significant competitive advantage for solar mills compared to incumbents and should be explored further.

Maximising utilisation is vital for solar-powered productive-use appliances. To maximise utilisation there are several technology lever that can be explored.

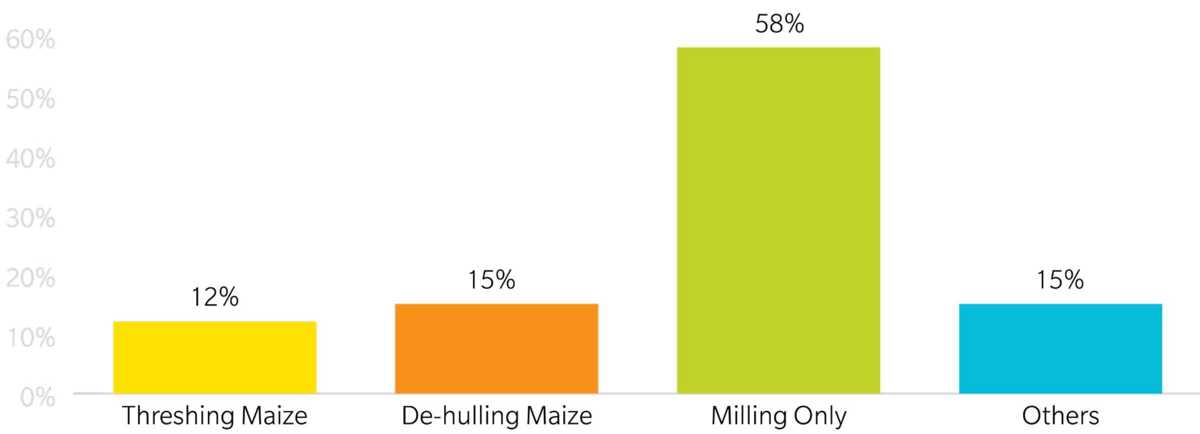
- **Use of battery-coupled solar mils.** Given a choice between a cheaper direct-drive solar mill and a battery-coupled solar mill, 96% of mill operators would still prefer the latter. Battery-coupled mills (even at double the capital cost) enable miller increase utilisation by milling at any time of the day and offer additional energy services.

- **Solar mills – particularly battery-coupled options – could offer an advantage to diesel mills in their ability to run continuously.** Diesel mills require modifications to the engine cooling system to run continuously. Nineteen out of the 24 diesel mill owners could run their machines continuously after adding a cooling reservoir in line with the engine radiator, as shown in Figure 5. Without this modification, mills can only run for three continuous hours on average. However, this modification presents a safety risk of burns from the hot water involved in the process, as well as a higher risk of machine failure due to the alteration of intended operation configuration. Though the continuous operation of the solar mill was not directly examined during this study, observations during functional testing were promising. Further research is needed to understand the effect of continuous runtimes on durability and operations of solar mills.

Figure 5: Water cooling modification on diesel mill, source E4I

- **Multi-functionality for solar mills is essential in ensuring maximum utilisation (thus increased profitability) for mill owners, a broader market reach for a larger distributor customer base and a competitive edge to incumbent diesel mills.** Solar mills capable of milling a variety of grains and performing other functions, such as hulling and threshing, have the

Figure 6: Survey Results on how diesel mills are used in maize processing.



potential to increase the income streams for mill operators around different seasons. Fifty-eight percent of diesel mill operators interviewed use their mills solely for milling, and primarily for maize milling. Other minority uses include cassava milling, millet milling and fibre processing. Solar mills may be designed to mill the produce available in the target market and consider having complementary appliances such as hullers. Distributors stocking a product with multiple use cases can unlock reach into a broader market, which better justifies adding it to their product portfolio.

Though solar mills are easy to operate, they also have to be easy to repair, troubleshoot and maintain for successful adoption. Respondents who saw the solar mill in person were impressed by the push-start button compared to the manual hand cranking required to start diesel mills. The labour-intensive and difficult manual cranking of diesel mills can inhibit the participation of women and people with disabilities in the milling business. The solar mill is, in contrast, a user-friendly design that allows women and persons living with a disability to perform essential operation and maintenance activities. Future iterations should maintain this ease of use.

For repair and maintenance, 77% of diesel mill operators rely on independent fundis.[55] Only 18% of the operators carry out light-touch maintenance themselves, such as replacing oil and screens and routine engine maintenance. Fundis usually operate within villages or in neighbouring villages or trade centres. All deployed solar mills had technical issues requiring intervention on in-country partner (see Table 9), since repair an independent maintenance infrastructure for this new mills has not yet emerged. However, the number and severity of the challenges experienced by solar mill owners was less that of diesel mill owners.

Since most potential mill owners would only attempt light-touch maintenance, solar mills need to be robust and easy to maintain. For example, the most common screen sizes used across all milling operations are the 0.8mm and the 1.0mm variants. These screens provide the desired flour finesses for the region's preference. The G2 mill uses a 1.0mm screen size customized to the shape of the milling chamber for efficiency gains. The shape of the chamber used in the G2 mill is very different from what is commonly used in diesel and electric mills– making it a challenge to acquire off-the-shelf spares. Manufacturers may choose to explore the potential of designing mills that are compatible with existing diesel mill spare parts that are readily available in the market.

Incorporating remote monitoring systems (RMS) in solar systems plays a crucial role in capturing data for predictive maintenance and further technology development. Data around energy generation and consumption, as well as battery usage could help to analyse the system performance. This would also be beneficial to distributors looking to bundle solar mills with other productive use appliances, as it would help with learnings on other potential services to provide local communities based on current demand. One in-country partner also stated that they need the data on solar mill usage patterns to investigate their customers' ability to meet their monthly payment obligations, given they have a PAYG arrangement with their customers.

The product package offered in the market should maximise value addition to both the distributor and the mill owner. In-country partners identified a solar milling kit, designed as a modular system, as the preferable technology bundle. The solar mill manufacturer would partner with local solar companies or distributors and supply the solar milling kit, i.e. the mill, motor and controls. The partner would provide the solar panel plus related components and assemble the system. The final solar milling kit would be designed as a modular system, which supports a combination of different functionalities apart from grinding cereals, e.g. a battery charging set or a water pump set. For example, this model is employed by SeineTech Ltd,[56] a solar-mill manufacturer whose partners with local solar companies or distributors supplying them with their solar milling kit, i.e. the mill, motor and controls. Their partners provide the solar panel plus related components and assembles the system. This model would allow distributors to generate more revenue through the sale of solar equipment they already stock. Distributors can also bundle solar mills with other appliances they stock, such as televisions and other productive use appliances, to again increase the revenue potential. More research need to be done on the effect on payback period of bundling additional appliances.

Solar mills meet higher safety and health standards for energised and moving machines than incumbent diesel mills. ESMAP[57] defines essential energy supply as being adequate in quantity, available when needed, of good quality,

Table 9: Distinctions between direct-driven and battery-coupled solar mills

Country	Technical Issue	Outcome
Kenya	Screen broken during first use	Screen had been provided by the manufacturer, but expertise was needed for the replacement
Kenya	Controller settings	Mill could not run due to shortage of power from the controller. In-country partners were advised on necessary changes required by the manufacturer
Uganda	Mill shut down	It was not clear why the mill ceased operations, but the operator needed better training to handle any technical issues.

55. Local, informal repair shops and personnel, majority of whom have built up repair experience from informal apprenticeships.
56. Also known as Solar Milling.
57. https://www.esmap.org/

SOLAR MILL IN UGANDA

Location: Mayuge District, Uganda

Name of owner: Simon Kahania

Milling experience: 5 yrs. of experience operating a diesel mill

Ownership model: Single owner enterprise

Operational model: Family members operate the mill

Energy system: 1kWp solar PV & 9.6kWp storage

Acquisition model: Mill issued as a demo under a UNCDF program for three months

Operational experience:

Simon uses his diesel mill to process maize and cassava, while his solar mill is used to mill millet only. He felt that the throughput of the solar mill when milling maize (32kg/hr) was low and not satisfying his customers. When milling millet, the throughput of the solar mill was higher (about 66kg/hr.) and acceptable to customers.

Simon also has a hulling machine that runs in line with his diesel mill. Customers in his village prefer hulled grain flour. Customers, therefore, prefer the use of the diesel mill as it incorporates this capability. Households and institutions only milled at the solar mill for whole grain flour used for cooking porridge.

The presence of battery storage allows the operator to work in the evening (low insolation) for about four hours.

The operator put the mill in one of the rooms of his compound and mounted panels on the roof. No extra work was done in the room.

Revenue from the solar mill was low as customers milling millet and maize for porridge were few and far between. He did not have any obligation to pay for the mill, so all the income from the solar mill was additional revenue to him.

Due to his experience operating a diesel mill, he was able to perform basic troubleshooting and repairs on the solar mill.

"I would love to buy this machine if the speed and output were faster and bigger respectively"

- Simon Kahania

Figure 7: Solar mill in business room.

Figure 8: Diesel mill operated by Simon

reliable, convenient, affordable, legal, healthy and safe. Field and operational experience has shown that of these energy supply aspects, health and safety, particularly at the consumer level, are less emphasised compared to the other aspects of energy supply. Diesel mills seen in the field have uncovered pulley belts, uncovered energised parts and no dust and noise inhibitors. Mills should be safe for operators, customers and repair personnel. The main risks associated with mills include risk of electric shocks, burns from heat produced, open pulley belts, noise and fires from poor handling of fuels. Manufacturers should test and ensure their products are free of potential risks that could harm operators or affect their operations due to the remote locations of deployment.

The Supply Chain

In our analysis of the supply chain, we considered the downstream provision of products and services to clients (in-country partners and mill operators). In this case, the supply chain involves sourcing, manufacture, assembly, distribution of solar mills and their spares and on boarding activities, such as training.

More research is needed make shipping and importation guidelines as well as existing tax and duty exemptions for agricultural processing machinery. The solar components, motors and controllers are mostly imported from Europe and Asia. Casing and other mechanical parts can be sourced locally in the region. For example, the solar mill was designed in Kenya and sourced from China. Movement of the mills across the border was challenging due to the unclear processed by country revenue authorities. In Tanzania, Kenya and Uganda, solar equipment is value-added tax (VAT)-exempt. However, the definition of "solar equipment" does not cover appliances. Information on appliance tax and duty exemption is difficult to acquire and application of exemptions is inconsistent. More research to evidence available incentives and exemptions for agricultural processing machines is needed to ease the movement of crucial appliances to where they are needed. One resource available is a shipping guide published by the Efficiency for Access Coalition.[58]

Regulations relevant to the solar maize milling sector are centred on the crop type, business operations and health and safety. Maize is heavily governed in Kenya, Uganda and Tanzania. In these countries, governments oversee the supply and storage of the crop. This is necessitated by the staple nature of maize in these countries and need to ensure prices and supply are cushioned from external shocks. Health licenses are required in some localities for a business to handle food items. Businesses must be registered with the specific country registrar. Although licenses are needed, most mill operators in rural areas do not pay for them due to lack of knowledge or indifference. For example, 70% of the respondents to our survey did not have health or business licenses.

In the East Africa, there are established channels for mill supply and precedents for selling mills through distributors and agents. Solar mills should leverage existing established distribution channels – with distributors such as the in-country partners of this study as the primary channel. Our interviews with in-country partners indicated that they use for business-to-business (B2B) and business-to-consumer (B2C) models to deliver products to their customers. Local distributors of off-grid energy products have trusted names and branches in many regions. Their wide networks of agents who complete last-mile distribution can create awareness for new products like solar mills in more remote villages. Local off-grid energy product distributors can also offer technical and product support to customers. Local distributors' main consideration in selecting sources for new product lines is the support provided by their suppliers/manufacturers. They tend to favour suppliers who provide training and product support services, like warranties, as it enables them to support their customers effectively. In general, manufacturers with in-country operations, such as local assembly points, warehouses and service centres would be the best fit for off-grid energy product distributors.

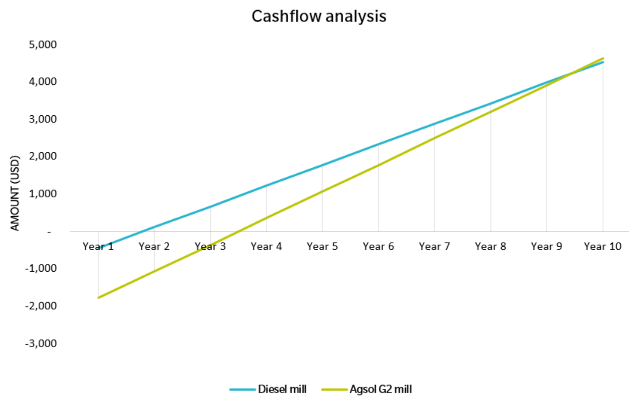
Product support and after-sale services through training, warranties, provision of spare parts and related services will be essential for the successful uptake of solar mills. The availability of such support was a factor that the majority of diesel mill operators considered when making a purchase (78% in Tanzania and 100% in Uganda). Solar mill manufacturers must ensure spare parts are available and product support is guaranteed. In-country partners in the pilot offered installation services, warranties and helplines to installation teams, which eased the process of seeking support. For distributors and third-party repair and maintenance organisations, bulk purchases of equipment and spares can reduce the overall cost of the equipment. Diesel mill suppliers benefit from economies of scale. Once a product is proven viable, distributors import or manufacture in bulk. The provision of spare parts is a crucial. Manufacturers should consider having dealers stock their spare parts through service packs.

Financing

The capital cost of the solar mill was a concern for prospective owners. All potential solar mill owners interviewed felt that the average cost of USD 2,500 quoted for the mill by in-country partners was prohibitively high compared to a regional average of USD 1,300 for diesel mills. Potential mill owners were willing to pay an average of USD 1,400 for a solar mill with a throughput of 120 – 150 kg/hr. (comparable to diesel mills). We analysed a business case using a 20kW diesel mill (most common size) and the G2 mill (Annex 2). The solar mill does not breakeven with the diesel mill until year 9 (see Figure 9), which is the end-of-life for the milling sections of both mills. It should be noted that some components of the solar mill (like the BLDC motor and PV modules) may still be within their operational life and may be reused.

58. Efficiency for Access, Practical Guidelines for Shipping Off-Grid Appliances Report, 2019.

Figure 9: Breakeven analysis of G2 mill and diesel mill



Solar mill owners may also have to bear additional costs of setting up a viable, secure room for housing the mill and the solar equipment. Diesel mill operators place their mills in lockable rooms or under makeshift sheds. For solar mills, a room with a secure and robust roof to fasten the solar panels is needed. The mill similarly needs to be in a lockable room for security purposes. Customers, therefore, must rent secure rooms or build or upgrade rooms for the purposes of establishing a solar milling business. A solar mill customer in Kenya had to upgrade a room next to their house to accommodate a solar mill, for example, which comes at a cost to the customer. When marketing solar mills, it should be communicated to customers that such a requirement will need be considered.

Equipment financing is a critical component of enterprise development. The high capital requirements of solar mills and its components (e.g. solar panels, control system and batteries) are prohibitively expensive to potential solar mill entrepreneurs, especially those in off-grid areas. These entrepreneurs operate in an ecosystem that lacks financial infrastructure and formal – or even informal – financial institutions within their vicinity to access credit. Further, these entrepreneurs also lack experience and skills in accessing finance. Where traditional forms of lending institutions do exist, their lack of knowledge of the perceived risk with renewable energy has, to a certain extent, discouraged them to finance the sector. Different options for raising capital are explored in Table 10.

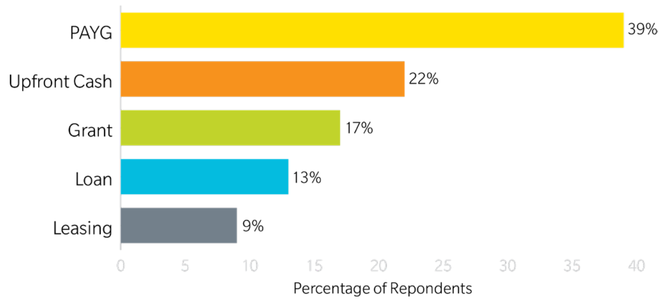
PAYG is a preferred mode of acquisition for off-grid appliances in rural areas, as many potential mill owners can barely afford deposits, let alone full cash payments. Most potential solar mill owners would prefer to acquire solar mills under a PAYG scheme since it allows for payment in small instalments over an extended period. The two mills purchased in Kenya were offered under a PAYG scheme because interested buyers indicated that they could not afford a full upfront cash payment. Raising the 10% deposit required by Mwezi Solar was a challenge for the two customers. They had to sell some domestic assets to afford the USD 250 deposit. In Uganda, a full upfront cash payment is required before delivery. Interested customers could not raise the required amount to acquire the mills. For instalment payments, the credit tenor and instalment value depend on how much revenue the mill owner can generate from their business. In the business case modeled in Annex 2 – a G2 mill owner can pay a maximum of USD 59 per month for repayment. In-country partners would be willing to offer mills on a PAYG arrangement as they do on other off-grid appliances they sell.

Mill customers all pay for milling in cash. No use of mobile money was evident for the payment of milling services. However, payment to distributors under PAYG was made using mobile payments. Mwezi and Simusolar, who offer PAYG, register customers' accounts on mobile money platforms, customers then use these accounts to send money at each repayment date.

Table 10: Funding options for solar mills

Types of financing available	Opportunities	Barriers
PAYG	•Small instalments overcome affordability hurdle •Lowers credit risk for entrepreneurs	•Relatively expensive and high interest rates •Conditional flexibility of payments •Poor understanding of loan terms and conditions
Microfinance Institutions (MFIs)	•Access to credit •More favourable loan terms compared to traditional banks •No collateral required •Promotes a savings culture	•Loans can be expensive •Does not extend large loans
Table Banking	•No collateral required •Favourable interest rates •Tailored to members' needs	•Risk of defaulters •Borrowing is limited to small amounts
Mobile Lending/ Digital Loans	•No credit history required •No collateral required •Fast and easy access to credit •Financial inclusion	•Loans can be expensive •Deception by lenders •East to fall into a vicious cycle
Internal Funding	•More ownership •More control •Little to no interest period	•Slow access to funds •Increases risk of bankruptcy

Figure 10: Preferred acquisition channels for a solar mill



The preference for PAYG, leasing and loans (Figure 10) indicates that **there is a consumer financial gap for acquiring solar mills.** Interested buyers are not able to provide upfront cash payments. Potential solar mill owners need credit facilities, either through distributors and other financial institutions or mechanisms to bridge the affordability gap. Distributors may need to create linkages with financial institutions to offer products on credit. Further, distributor financing through investment, debt facilities or other financing mechanisms is critical to the uptake of solar milling because distributors wills struggle to maintain working capital if they offer these expensive appliances on credit to their customers.

Business Models

In addition to addressing technology and financing challenges, the success of solar milling also hinges on the right downstream business model for the solar mill owner. At the most basic level, solar mill operators can choose to offer **milling as a service, sell milled flour as a product or both.** In the study areas milling as service was offered at USD 0.044/kg in Tanzania, USD 0.048/kg in Kenya and USD 0.041/kg in Uganda. Pre-milled flour was not offered in any location because customers do not trust the quality of flour, preferring to grind their own grain. Some operators stock maize in their premises which they sell to customers who then pay for it to be milled. NREL & E4I identified that selling flour is more profitable but less commonly practiced in an earlier report.

Given the milling fee and previously discussed high cost of system, milling flour alone using the G2 mill at its current capacity is not a viable business model. An analysis of payback periods for a mill considering capital costs and throughput for a mill is highlighted in Table 11.

This shows that to approach commercial viability, solar milling must maximise utilisation of the mill and any ancillary systems to increase revenues. Examples of business models that increase utilisation of mills are:

- **Provision of additional energy services.** Since milling is an intermittent activity, the G2 mill was designed to offer additional energy services that could utilise energy when the mill is not in operation. These services can leverage the battery system supplied with the solar mill, possibly improving the unit economics for the mill operator. None of the diesel operators interviewed offered any additional energy services at their premises. However, 52% of them agreed that having such services had the potential to increase business income. Offering services such as phone charging, cold drinks and video shows could boost an operator's revenue and attract more customers. It is worth noting that there would be competition for such additional services in the rural markets, given increasing penetration of off-grid supported businesses. The provision of additional energy services requires an additional investment, which may further affect the business case for a solar mill.

- **Demand-side management to ensure solar mills operate during peak sun hours.** The solar mill has the highest production rate when it is operated during peak sun hours. However, milling patterns do not align with peak sun hours. Demand for milling services peaks prior to conventional mealtimes (before lunch, 10am – 1pm, and before the evening meal, 5pm – 7pm). Training and business models that can align customer behaviour and milling time to a planned schedule for maximum production would be ideal. Pick and drop models as explored in the market section are unpopular, so solar mill owners will need more innovative business models to match milling demand with optimal milling times.

Table 11: Payback period analysis for a G2 mill

		Capex of the solar stand-alone (USD)							
	3.5	1000	2000	3000	4000	5000	6000	7000	8000
Amount milled per day (Kg)	100	1.95	3.91	5.86	7.82	9.77	11.72	13.68	15.63
	150	1.30	2.61	3.91	5.21	6.51	7.82	9.12	10.42
	200	0.98	1.95	2.93	3.91	4.88	5.86	6.84	7.82
	250	0.78	1.56	2.34	3.13	3.91	4.69	5.47	6.25
	300	0.65	1.30	1.95	2.61	3.26	3.91	4.56	5.21

SOLAR MILL SOLD IN KENYA

Location: Nyakach District, Kenya

Name of owner: Thomas Oginga

Milling experience: Wife operated a women's group diesel mill for 5 years

Ownership model: Single owner enterprise

Operational model: Wife and farmhand operate the mill at their own compound

Energy system: 0.5kWp solar PV & 4.8kWp storage

Acquisition model: PAYG priced at a total price of $2,500. 10% deposit before delivery and equal monthly instalments of $93.75 for 24 months with a 2-month grace period after delivery

Operational experience:

The mill had technical issues after installation. Settings on the motor controller were incorrect during installation such that the motor did not run. The mill manufacturer supported the installation technicians in resolving this issue.

A stone fed into the mill mistakenly damaged the mill's screen. The broken screen affected the quality of flour produced as large particles passed through the screen opening.

Thomas built a stall to accommodate the installation - he financed this through the balance of funds he had after selling some of his livestock and paying off the deposit.

Thomas has complained that the revenue he gets from milling is not enough to make the repayment obligations. He sells vegetables to milling customers to generate additional revenue. It was, however, too early to make any conclusions, as customers in the village were not aware of the mill well enough. Due to the technical challenges encountered, Thomas had not made any repayments by the time this report was prepared – his grace period was extended and consideration will be made on replacing this mill with a Gen 3 mill if required.

"The grace period we were given to operate the mill is too short. Since my solar mill sieve has broken down, it should be repaired immediately in order to enhance its function. The organisation should train some individual at local level to help in repairing the solar mill. Otherwise am so much grateful with Solar mill initiative and innovation. Thank you."

- Thomas Oginga

Figure 11: Solar mill in business premises.

Figure 12: Diesel mill operated by a women's group

Off grid solar milling could leverage existing innovative business models to improve their financial viability by reducing capital expenditure requirements. Examples include off grid solar malls or off-grid productive use zones. Organisations such as Solarkiosk[59] have developed off grid malls that are powered by solar PV systems where several enterprises are hosted. Providing a viable mill that can utilise the power can add more value to the malls while increasing a market for manufacturers to consider.

The Market

The off-grid milling market prefers solar PV systems to fuel-based energy sources. 95% of the diesel and solar mill owners interviewed prefer solar mills to the currently available diesel mills. Diesel mill owners perceived the use of solar in milling as a solution to reducing operational business costs and increasing their income. Solar mill owners and their customers were satisfied that the solar mill did not emit smoke or produce much noise. The main concerns for potential solar mill owners were the capital cost and low throughput. Additionally, there were concerns about the effect of weather on solar mill operation. Eighty percent of those surveyed believe that weather will be a major hindrance to the performance of solar mills. This could be from their own experience or that of others in the community using solar PV systems. Additionally, 20% of respondents are concerned with the availability of spare parts and number qualified technicians for repair and maintenance. Currently mill owners get their spare parts from the nearest town to their villages but were uncertain whether spares for a solar mill would be locally available. Potential solar mill owners stated that they would consider purchasing a solar mill if the price was right and the mill's throughput could meet customer demand.

Potential mill owners list throughput (35%), energy efficiency (19%) and cost (18%) as the primary considerations when purchasing a mill. Respondents in Uganda were highly sensitive to the purchase cost. In Kenya, potential customers were more sensitive to running cost. While in Tanzania, there was equal consideration of both purchase and running cost. Sensitisation on the operational benefits of solar mills is required in markets where there is a significant concern about the purchase cost. Simusolar highlighted that before making any sale of their solar water pumps, they must first prove the economic benefits of their products to customers. This strategy has helped increase sales and improve customer awareness. When marking mills, more education and training on the use of solar appliances for increased revenue should be offered to potential customers.

Milling customers, on the other hand, consider proximity (33%), fineness of flour produced (27%) and throughput (11%) as the primary considerations when selecting where to mill. Other considerations were good customer service, availability,[60] pricing discounts and de-hulling services.[61] Women and children make up 96% of milling customers. For them, proximity is the foremost consideration, as most wish to avoid walking long distances with heavy grains or flour (up to 10kg) on their backs. Customers found the quality of flour from the solar mill acceptable and most preferred it over flour from diesel mills. The price of milling does not rank highly for customers since it is constant regardless of the milling technology. In the region, the service cost of milling is USD 0.045 per kilogram of maize. Mill owners need to have mills that offer value to their customers. Therefore, manufacturers should prioritise requisite mill throughput and quality of flour in the design of mills.

There is competition for milling customers in the villages surveyed, reducing the catchment area for each individual mill owner. Twenty-two out of 24 villages surveyed had between two and four mills located within a 1 km radius from each other. Each mill served approximately

Figure 13: Responses on presumed benefits of solar mills

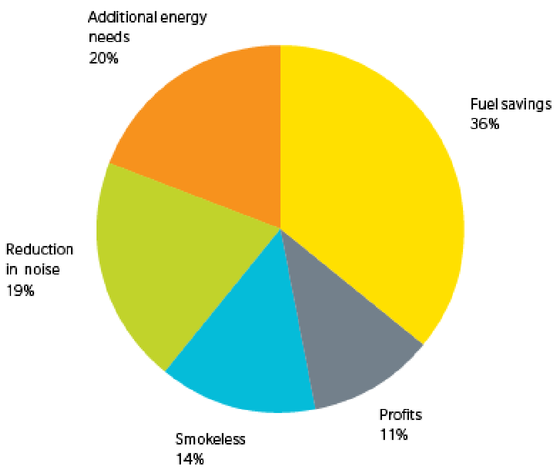
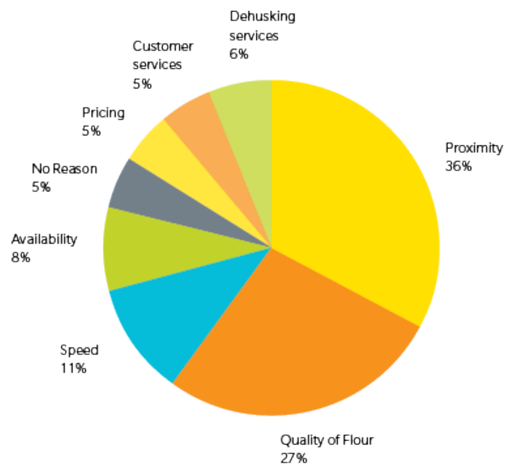


Figure 14: Consideration by milling customers when choosing where to mill



59. Solarkiosk is a trading platform, a system integrator, a service provider and a business incubator. They combine quality solar products with turnkey solutions and provide services to create sustainable businesses in off-grid frontier markets worldwide. We have deployed approx. 250 E-HUBBs worldwide in 15 countries, reaching approx. 5m people. (https://www.solarkiosk.eu/).

60. Availability of the operator when a customer wants to mill.

61. A de-hulling machine is coupled using a belt, to the existing diesel engine when de-hulling services are needed. The belt can be transferred to operate various machines. This was identified in Uganda.

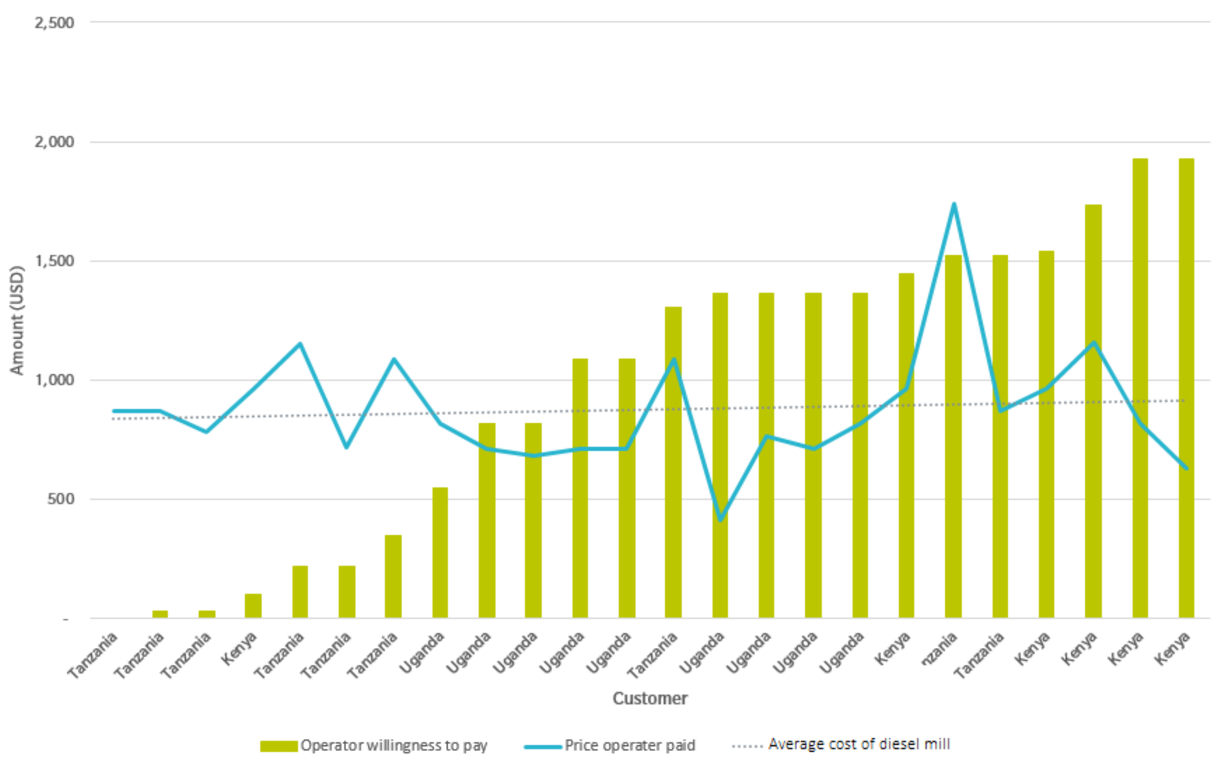
15 – 50 households depending on the village population size and density. Each household mills 6-10 kg per week. Due to competition for the provision of milling services, operators must offer competitive advantage to win over customers. None of the operators reported customers from outside the village. Given the stiff competition for customers, it would be difficult for a new business to gain market share in a village with established millers. For solar mills, the most likely customers in the near term are:

- Off-grid diesel mill operators whose engines have reached the end of life. These individuals have experience in the business as well as performing operations and maintenance on a mill.

- Institutions such as schools, hospitals and prisons that offer food in large quantities. Schools typically mill from trading centres in bulk. Having a mill within their vicinity can save them time and money in the long run. In addition, such institutions may be better placed to shoulder the upfront costs of solar mills.

Potential mill owners are willing to pay significantly more for solar mills than what they paid for their diesel mills as long as the solar mill has the same throughput as the diesel mills. To significantly increase a solar mill's instantaneous throughput (kg/hr) would require use of use larger BLDC motors which would push the cost of the solar milling systems even further up. For daily increased daily production millers would have to increase operating hours which can only be supported by a robust, high-quality machine and increased efficiency. Current solar mills, though durable and somewhat efficient, are very expensive. Although efficiency gains could mitigate the cost increase of larger motors or higher quality motors, a more holistic, multi-pronged intervention on technology, supply chains and business models is needed to significantly bring down solar mill costs.

Figure 15: Relationship between cost of diesel mills and price respondents were willing to pay for a solar mill



Stand-alone solar PV powered mills are not yet commercially viable because they do not meet the market requirements that allow them to compete with incumbent diesel mills. More research and development, field testing and pilots are needed to push the technology towards the cost, throughput and efficiency sweet point for commercial viability. Prototype pilot deployment is crucial because it allows customers to give meaningful feedback on the technology and how it operates. Deployment uncovers new crucial information about the product and service the technology offers.

There may be a viable market for stand-alone solar milling, but high price sensitivity is a key barrier to entry. Due to the current penetration of off-grid solar products such as solar home systems and solar lanterns in the East African market, customers are more aware of the cost benefits of using solar products. The benefits of solar milling would likely be highly appreciated with adequate community sensitisation. Communities, however, remain quite sensitive to prices, owing to their low-income threshold and seasonal fluctuations of revenues from their predominantly agricultural activities. One of the main benefits reported by mill operators was the savings on fuel compared to using diesel-powered mills. Life cycle cost analyses can present the case for solar-powered mills when compared to the incumbent.

Compatibility and cost-effectiveness between the solar mill and energy system is a crucial determinant of system efficiency and operability. The cost of energy for stand-alone solar is still prohibitively high compared to incumbents. Opportunities exist for the application of super-efficient motors for solar mills, which can bring down the effective cost of the mill by providing more output that matches demand. The development of improved technologies therefore needs more research and development in design and deployment.

The solar milling sector lacks access to sufficient risk capital. Recently, there seems to be significant funding going into the private off-grid sector, particularly for solar lanterns and solar home systems (including working capital for PAYG). Other activities like stand-alone solar systems, mini-grids and cookstoves receive less funding. Moreover, many funding sources that became available recently offer debt funding and thus are only accessible to operational, more mature companies. There is also a trend of funders targeting the same players and available capital for only a select small pool of companies.

Recommendations to Donors and Investors

Make risk capital available to entrepreneurs, suppliers and manufacturers to enable them to fund research and development for more efficient solar mills and specific market-led design. For start-ups and smaller companies, there is little risk capital available that would enable them to establish operations and grow. Often, companies set up operations with their own funds/equity and some smaller share of grant funding. Accessing risk capital to take the next step is a challenge.

Incentives for early adopters should be considered when piloting appliances. Early adopters, such as distributors, risk their reputation to customers when they take on a productive use appliance whose performance is not yet validated in the market. Rewards of adopting should be commensurate to this risk. In the future, they could become good brand ambassadors for the products if successful in the testing phase. Incentives could include pricing discounts, free servicing and a direct line to the manufacturer to provide input on product design and performance of future iterations. Customers who acquire the pilot version of the mill run a risk of operating redundant machines with operational challenges if products are improved. This is detrimental to the distributor-mill owner relationship and should be provisioned against.

Build programs that bring energy and agricultural actors together to develop holistic approaches to the development of PU equipment. Much of the development of agro-processing solutions is done in silos, whereby some aspects of the design may not be considered. Solution developers in the agricultural, energy and extension services sectors need to work collaboratively in development of feasible products and services. These include agricultural extension officers who promote proper agricultural produce handling techniques, energy product manufacturers and suppliers who enable energy reliant technologies and manufacturers of agro-processing appliances

Potential solar mill operators need credit financing solutions to purchase solar mills. Two of the in-country partners in this stud offered their solar PV products on a PAYG basis, where they cover the cost of credit covered internally. This would be highly risky for a larger and more expensive product, such as a solar mill. It would be less feasible for companies to commit a substantial amount of money on a credit basis for several solar mills at once. It is worth then looking at the potential to engage third-party finance providers such as local micro-finance institutions (MFIs) or other credit providers to reduce risks and maintain their needed cash flows.

The development of field-testing protocols by research organisations for solar mills is necessary. Over this pilot, we relied on a testing protocol developed for laboratory testing. Field tests are necessary to validate the feasibility of technologies. A field testing protocol should be developed.

Recommendations to Policymakers

Policymakers should consider the integration of agricultural equipment provision into national policies. More funding and resources should be availed to resourcing and training research and development centres for productive use appliances.

Governments should clarify the tax and duty exemptions that exist for off-grid agricultural appliances. This reduces the downstream cost of the mills and passes the benefits to the end-user.

Recommendations to Suppliers and Manufacturers

Companies should undertake market research in the markets they are interested in reaching. The economic viability challenge faced during the pilot portions of this study centres on the solar mill inability to meet operators and customer requirements. A bottom-up approach in designing a product for the off-grid market increases the chances of product competitiveness and market acceptance. This approach is quite relevant for the solar milling technology, a novel technology in the East African market aimed at providing a competitive edge to the already mature diesel-powered mills market.

Distributors should consider the promotion of access to finance by creating linkages that enable potential solar mill owners to access credit from financial institutions. These linkages can be directly from financial institutions or through distributors themselves offering products on credit. Use of credit -scoring tools can be employed by distributors to identify potential customers who qualify for credit.

Do more research and development to develop more efficient machines that are viable in the market. This is necessary as the current prototypes for solar mills are not viable. There are opportunities, however, to increase the efficiency of mills through the application of high performance motor, hammers and controllers, as well as effective balancing of the equipment used to provide an efficient machine. However, these innovations must be balanced with costs to avoided adverse impact the affordability of the final product by customers.

Undertake market development and awareness campaigns to generate interest in currently untapped markets. Awareness of solar mills was not absent during our field visits. Distributors need to create awareness to create demand for alternative mills. Respondents encountered during field visits were not aware of the existence of solar mills in their locations. They were very receptive to using solar mills due to the operational benefits they identified. Awareness campaigns are needed in the market when solar mills are commercially launched; this can be done through demo sites at the distributors' offices and use of agricultural extension officers to disseminate the message.

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Criteria for identifying potential solar mill operators and locations of the respondents

Item	Relevance	Selection Criteria
Location	Geographical locations of the potential solar mill operators	• Should be in a village that farms maize, millet and/or cassava • Village where milling is currently practiced. • Village should be in an off-grid area (at least 5km away from nearest grid lines) • Village with >250 households within 4 km
Milling experience	Experienced mill operators provide better insight on the technology and business responses required	• Respondent to be a current off-grid mill operator • Should be operating in a central location in the village
Milling output	Milling output should be equal to what is available in literature review	• Mill operator milling >200kgs of flour per day
Market	Mill operator contact with his/her immediate customers	• Operator in village where customers are internal • Operator in a village with more than one mill (where possible)
Opinion from in-country partners	In-country partners advice on the potential regions and individuals for consideration	• Current customer to the in-country partners • Individuals who have expressed interest in acquiring a solar mill to the in-country partner.

KENYA

Maize production:
3.19 million tones (2017)
Electrification rate: 73.42%(2018)
Population: 52.57 million(2019)

Busia

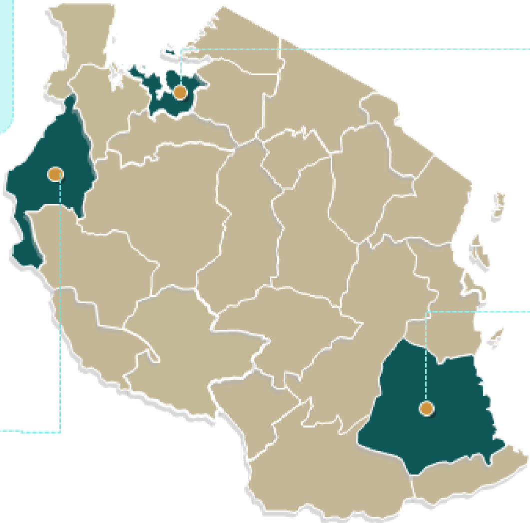
Maize production: 72,572Mt (2014)
Electrification rate: 6.0%
Population: 744k (2009)

Siaya

Maize production: 160,636MT (2017)
Electrification rate: 4.3%
Population: 842k (2009)

TANZANIA

Maize production: 6 million T (2015)
Electrification rate: 32.8% (2016)
Population: 58.01 million (2019)



Mwanza Region

Maize production: 202kT (2009)
Electrification rate: 5.56% (2002)
Population: 2.773 million (2012)

Lindi Region

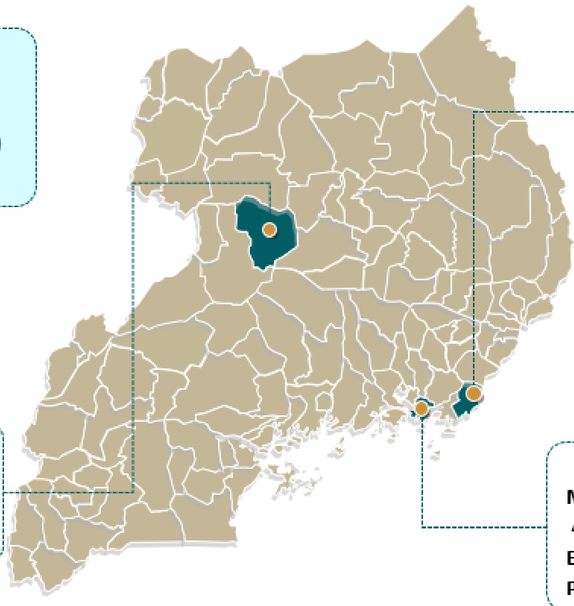
Maize production: 89kT (2009)
Electrification rate: 24.5% (2016)
Population: 865k(2012)

Kigoma Region

Maize production: 171kT (2009)
Electrification rate: 16.2% (2016)
Population: 2.128 million (2012)

UGANDA

Maize production:
3.08 million T (2016)
Electrification rate: 26.7% (2016)
Population: 42.86 million(2017)



Busia

Maize production: 10,701 Mt(2008/09)
Electrification rate: 12.3% (2014)
Population: 324k(2014)

Kiryandongo

Maize production: No data
Electrification rate: 12.5% (2014)
Population: 266k(2014)

Mayuge

Maize production:
41,982 Mt (2008/09)
Electrification rate: 9.7% (2014)
Population:473k (2014)

Lifetime cost Comparison of diesel mills and G2 mill

Description	Diesel Mill	G2 Mill
Production		
CAPEX (USD)	1,000	2,500
Life (yrs.)	10	10
Daily production (kg)	300	140
Throughput (kg/hr.)	150	32.7
Average operating hours per day (hrs.)	2	4.3
Annual production (kg p.a.)	109,500	51,100
Availability/seasonality factor (%)	85%	80%
Annual production (kg)	93,075	40,880
Power Requirement		
Size of motor (kW)	20	1.2
Loading factor (%) - 80% for diesel	16	1.2
Revenue		
Price charged for milling (USD/kg)	0.045	0.045
Annual revenue (USD)	4,188	1,840
Lifetime revenue (USD)	41,884	18,396
Expenses		
Capex	1,000	2,500
Cost of diesel (USD p.a.)	2,555	-
Repair and maintenance (USD p.a.)	300	98
Labour costs (USD p.a.)	780	780
Battery replacement (USD p.a.)	-	250
Rent (USD p.a.)	-	-
Total expenses (USD p.a.)	3,635	1,128
Summary		
Annual profit (USD)	553	712
Payback period (years)	1.8	3.5

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CONTACT US

efficiencyforaccess.org

info@efficiencyforaccess.org

@EforA_Coalition