A2E

ACCESS TO ENERGY INSTITUTE

PRODUCTIVE USE REPORT

EVALUATION OF SOLAR POWERED AGRICULTURAL TECHNOLOGIES FOR PRODUCTIVE-USE APPLICATIONS: A MODELING APPROACH

AUTHORS AND ACKNOWLEDGEMENTS

Lead Author: ELLIOT AVILA

Contributors: ADRIANA GARTIES, BINDE MOHAMED, JORDAN LIN

With special Thanks: Alfred Chengula, Jesse Oljange

The Access to Energy Institute strives to be the world's first charitable and collaborative research and development platform for the solar off-grid industry. Launched in 2019, the A2EI works with entrepreneurs, inventors, and organizations to support the development and research around solar powered appliances and energy related services.

The research was supported by Imara Tech, a Tanzania-based start-up that manufactures productive-use technology for rural smallholder farming communities.

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PREAMBLE

I could not tell you how many meetings I have been in where we sat around a table and brainstormed a list of agricultural machines that we thought could be solar-powered. Or conversations where someone asked me, 'So, exactly which agricultural technologies can run on solar?'

Those conversations always left me with mixed feelings. The idea of productive-use agricultural technology is such an enticing idea for so many of us, for so many good reasons: the job creation, the value addition, the environmental impact, the strengthening of rural communities.

But often it felt like we had more questions than answers, like we only had a murky understanding of the productive-use space. The potential for impact was clear, but the potential for implementation and scaling was inconclusive.

We have seen successes over the years and solar water pumps and cold chain technologies continue to be at the forefront of productive-use off-grid technology. Although still a maturing sub-sector, the conversations around these products have shifted to be less about whether a market exists and more about how best to capture it.

For other products, there remains uncertainty. The verdict is still out on solar mills, egg incubators, and the rest of the laundry list. The success stories we hear often feel like hard won exceptions to the rule: what works for one organization, one customer, one location, does not necessarily translate into broad success. The evidence is still being gathered.

This research was motivated by a desire for conclusive answers that would lay these kinds of searching conversations to rest. I was looking for a roadmap, something that would steer us toward the products that had the highest potential to scale. Just as importantly, I wanted to know what wasn't going to work.

So in May 2019, A2EI surveyed stakeholders from a cross-section of the off-grid energy sector and asked them what products they wanted answers on. We took that list, cut it down, added some of our own favorites, and got to work. The result of that endeavor is this paper.

It is fair to say that I underestimated how ambitious the scope of work I originally envisioned really was. Each of the resulting ten sections could have been written as a stand-alone paper and in total, there are over 100 instances of variables used in this paper. Each value we assigned required background data and research so that our claims could stand up to scrutiny, of which there has been plenty.

My original objective was to give readers conclusive and clear direction on whether each of the technologies have potential to be scaled as a productive-use product, which was only partly achieved. The off-grid landscape is diverse and dynamic and requires nuance. Ultimately, we decided to limit our recommendations to Tanzania and to include many caveats among them.

However, we recognized there was value in the methodology that we used throughout the paper. By making all of our assumptions transparent, our discussions around this topic have become much richer.

And so the most important thing to come out of this paper is not the business model evaluations, but the recognition that a model is essential to any conversation on productive-use. The modeling approach allows for a high level of detail, creates transparency, and makes it simple to consider different scenarios.

Modeling shouldn't just be one of the tools we use to look at productive-use, it should be the primary one.

As a result of this insight, the final version of this paper has been refocused around how and why we should integrate the business model approach into our work on productive-use, whether we are investors, entrepreneurs, distributors, product designers, or otherwise.

I am looking forward to closing this long chapter, not because of the many challenges it presented, but because of all the exciting work that is ahead. What will happen when we revisit old questions with new tools? For me, the process gave me my roadmap, and I'm excited to work on prototypes that I hope will be join a new wave of productive-use technologies – an audacious goal, but one worthy of the attempt.

Until next time,
Elliot Avila
Lead Author

#1 INTRODUCTION

INTRODUCTION

The objective of this research was to use a business modeling approach to identify opportunities for solar energy to be used productively in agricultural contexts.

A methodology for constructing and evaluating solar-powered, productive-use business models was developed. This methodology was then applied to ten agricultural processes in order to evaluate the market potential for different productive-use technologies in Tanzania.

For each agricultural process, a productive-use technology enabled business model was constructed using data collected from interviews conducted in Tanzania with operators of similar technologies and end-users such as farmers. Each business was modeled under three different tariffs using technical specifications collected from technical evaluations, third party research, and suppliers.

The business models were then evaluated based on criteria that revealed the attractiveness of the investing in the productive-use business, such as unit economics and other financial metrics. Businesses were further evaluated through criteria that assessed the desirability of products and services for end-users and the viability of the product to scale.

Insights on the factors influence productive-use potential were drawn from the ten use-case analyses and summarized so that other productive-use cases can be quickly assessed at a high level.

The effectiveness of the modeling approach was explored and recommendations were made for adapting the methodology to other contexts for other purposes. Suggestions were given for how the methodology may be used by stakeholders in the off-grid energy and agricultural sectors.

Spreadsheets containing all assumptions and calculations used in this research are available on the A2EI website so that readers can adapt the models.

STRUCTURE OF THE REPORT

This paper was originally written as an evaluation of 10 different solar-powered productive-use appliances. As it evolved, we recognized that for many readers, the true value of this piece of work was in the approach and methodology rather than the specific outcomes of the evaluations. Consequently, this paper has been modified to address a broader audience that wishes to adapt the approach here to their own contexts, while still preserving the original text.

The high-level structure of the paper is as follows:

#1 INTRODUCTION
This introduction section discusses the modeling approach, the background, why it is useful, and describes how it can be used by different stakeholders.

#2 METHODOLOGY
The methodology section describes the modeling approach used in the evaluation section.

#3 APPLICATION OF THE METHODOLOGY TO TANZANIA: EXECUTIVE SUMMARIES OF 10 TECHNOLOGIES
This part of the report provides short summaries of the evaluations of 10 solar-powered productive-use appliances in Tanzania.

#4 APPLICATION OF THE METHODOLOGY TO TANZANIA: ASSESSMENT OF 10 TECHNOLOGIES
The application part of this report provides full-length evaluations of 10 solar-powered productive-use appliances in Tanzania.

#5 CONCLUSIONS
The conclusion section of the report summarizes the learnings from the modeling approach and proposes a series of next steps for further investigations.

#6 ANNEXES
The annexes provide additional information, guides, and practical examples about adapting the modeling approach to different contexts.

BACKGROUND

Income as a Value Proposition

Why would a customer buy a solar-powered, productive-use technology? For entertainment? For environmental reasons?

We posit that the most important value proposition that productive-use technologies deliver to customers is the ability to earn income from the technology. Therefore, we can quantify the value proposition of productive-use technologies by assessing its business model.

This marks a fundamental difference between productive-use technologies and other categories of product, such as entertainment appliances. By modeling a productive-use business and evaluating its financial performance, we measure the value proposition in an objective way, which allows us to draw market insights without extensive market testing.

This conclusion forms the basis for this paper.

The Modeling Approach

A model is a representation of a system and we find them throughout our lives, from financial models to business models to engineering models and more. We use models as a tool to better our understanding of a system, both in terms of its inner workings and its outputs.

Modeling can be applied to productive-use technologies as well. By creating a business model of a productive-use technology business, we gain insights into how it functions and benefits users.

Reasons to Model Productive-use Technologies

There are many benefits of using a model for evaluating productive-use technologies. First, models can be used with assumptions that are based on any amount or quality of data, from blind guesses to rigorous data sets. This makes models particularly useful for emerging and fast-moving sectors where there may be limited established data to draw upon, such as the use of productive-use technologies in the off-grid energy sector.

Another benefit of models is that they force transparency. Making a model and its assumptions transparent helps keep ideas organized and makes concepts easily understood by external audiences. When working with innovations such as new productive-use technologies, having a clear and easy-to-understand idea makes it easier for that technology to be advanced.

One other important benefit of models for the productive-use sector is that they are easily and rapidly adjusted. Multiple scenarios can be viewed and assessed with a model, which is ideal for productive-use technologies where there are many uncertainties.

APPLICATIONS OF THE METHODOLOGY

Use Cases for Applications of Methodology

The methodology in this report is used to evaluate 10 different productive-use appliances, but can easily be adapted for use by other stakeholders in the off-grid energy sector. Below we discuss three different use-cases for this approach.

For Investors And Entrepreneurs:
Better Funding Outcomes For Productive-Use Technology

One of the primary uses of the methodology presented in this report is to use it as a tool for making informed investment and funding decisions around productive-use technologies. By making the business model the focal point of the discussion between entrepreneur and investor, assumptions are made transparent, which we believe benefits all parties involved.

Some tips for using the methodology in this way for funders:

- Have a model prepared in advance of any discussion. Spend the time to understand and become comfortable with the mechanics so they can be adjusted on the fly. Get a second opinion on the numbers – are all the figures convincing?
- Identify which of the assumptions are the most tenuous and challenge them. Is the business case still appealing if the assumptions are made more pessimistic? Conduct a scenario analysis to understand how the product performs outside of ideal conditions.
- Talk through and debate the criteria used in evaluating the productive-use business model. In this report, we use a $4 profit/day to benchmark attractive SME business investments, but this may not be appropriate in other contexts. Ask questions about the metrics used to measure success – are these the right ones? Why or why not?
- Be honest about where you have doubts. Weak points often become an important topic to address in a future engagement.

And some tips for entrepreneurs:

- Be transparent. You need to be a salesperson for your idea, but many people don't believe salespeople. Handhold your audience and take them step by step through your idea so that they see things the same way that you do.
- Use the model to solicit specific feedback on where your audience is getting stuck. Entrepreneurs often get turned down without a clear explanation why (or else never hear back at all). Have people point out where they are having trouble following along so you can adjust your approach.
- Create project plans that address the aspects of your product that are perceived as the riskiest. There might be a specific item that people have trouble believing ("Will someone really use your product for that many hours per day?") or there may be a general sense of doubt ("I'm not sure the product is going to last that long"). Your early-stage projects (and funding requests) should be directed at shoring up these weaknesses.

For Researchers:
Increasing the Utility of Research Done on New Product Pilots

Pilots are a useful method for capturing data on new products, but they have limitations.

In a pilot, we seek to capture data from a small sample (e.g. a handful of communities in northern Tanzania) and expect to extrapolate the results to a larger population (e.g. the entire off-grid population of Africa). A challenge that arises from this is that it is difficult to understand if and how pilot data and conclusions are relevant to different contexts. Are the results still useful if we change locations, product model, customer profile, power source, or any other variable?

The business model is the natural complement to the pilot. Where the pilot gives depth, rigidity and concrete data, the business model gives breadth, flexibility, and the freedom to test hypotheses on a whim.

Any studies conducted on pilots of productive-use appliances will be improved by the inclusion of a business model as part of the results, constructed from the data collected during the pilot. By including the model alongside the results, researchers allow readers to recreate the pilot on paper for their specific context.

For All of Us:
Identifying Opportunities for Innovation and Where to Go Next

Innovation is a response to a need. But what needs to happen to spur the adoption of productive-use technologies in off-grid areas? Should we prioritize R&D of energy-efficient technologies? Test new business models? Seek out financing innovations? Implement subsidies? Change policy?

Through our modeling approach, we gain deeper understanding of the challenges facing productive-use products and thus identify opportunities that are ripe for innovation.

For example, in our analysis of fruit dehydrators, we see strong unit economics but raise doubts that dehydrators can scale broadly through Tanzania due to the difficulty that operators have finding a market for the dried fruit. Viewed through an innovation lens, this becomes a problem framing statement that we can ideate around. Managing a dried fruit value chain might not play to the strengths of a solar distributor, but is exactly the kind of challenge that is being addressed by start-ups and NGOs in other agricultural value chains.

We see opportunities for innovation coming from many different sector stakeholders, not just product designers or solar companies.

As an organization focused on R&D and technology innovation, the A2EI used this modeling approach to identify what productive-use technologies we could improve through a product development process and make market-ready. Had we been another type of NGO, we might have chosen to develop a business skills program for women entrepreneurs using juice blenders. If we were a funder, we might have decided to subsidize flour milling fees for mills that serve small populations where the mill would otherwise be unprofitable. If we were starting new businesses, we might build contacts who can buy dried fruit in bulk.

The modeling approach shows us that there are many levers that influence the success of productive-use technologies. Few organizations will be positioned to move all of them, but most organizations working in this space will be able to move some of them.

#2 METHODOLOGY

RESEARCH OBJECTIVES

Summary of Research Objectives for Product Evaluations

The primary objective of this research is to identify opportunities for solar energy to be used profitably in agriculture-related businesses in Tanzania.

Specifically, we seek to:

- Evaluate ten different solar-powered technology use-cases and determine whether they can be operated profitably and what potential barriers to scale are associated with the product
- Make concrete recommendations to the off-grid energy sector about whether each of the ten technologies is scalable and to identify circumstances necessary for scaling
- Develop technology and market insights that can be used to guide future productive-use evaluations

METHODOLOGY

Getting Started

Selecting Productive-Use Cases for Research

Prior to the start of the research, a survey was conducted with a cross-section of stakeholders from the off-grid energy sector consisting of private sector representatives, donors, researchers, and NGOs. These stakeholders were asked to rank their interest in productive-use technologies for additional research. The highest ranked items were selected for inclusion in this research.

Structure of Productive-Use Cases

Each productive-use case has been structured similarly and has the following sections:

- Introduction
- Technology Overview
- Business Model
  - Overview of Business Model
  - Limitations of Modeling
  - Technology Inputs and Assumptions
  - Business Inputs and Assumptions
  - Calculations
  - Discussion of Results
- Conclusions

Additional sections are included throughout the research to provide additional context and insights.

Modeling Approach

The modeling approach can be broken down into two main steps: construction and analysis. In construction, we build our model by making assumptions about a technology and its usage in a business. In analysis, we evaluate our modeled businesses against performance metrics. The next sections describe a process for constructing and evaluating models for productive-use technologies.

Approach to the Development of Business Models

Business Models Structure

To begin constructing our business model, we first created the basic use-case for our technology. For example, we may choose to model an entrepreneur that provides oil pressing services to customers using a solar-powered expeller. This was done through a simple jobs-to-be-done framework, wherein users are described by their most pressing need that drives their actions.

Next, a set of assumptions was made to further develop the business models. The assumptions fell under three main categories:

Technology Assumptions: A productive-use technology was selected to be used in each business. Important technical specifications such as power consumption and throughput were determined based on a combination of manufacturer reported specifications, literature, and when possible field testing.

Business Assumptions: Essential business assumptions were made for each business, such as service price, material costs, and daily usage. These data points were based on data collected from field interviews done in Tanzania with end-users and business operators.

Energy Assumptions: The cost of solar electricity was modeled with a kilowatt-hour tariff.

These assumptions were laid out in a simple structure that gives written details beside a table that lists assumptions and their values. This structure was mirrored in a digital spreadsheet, which allowed the values to be changed easily and for calculations to be made.

Finally, each business was evaluated by its unit economics given on a per-hour basis. Revenue, operational costs, and gross profit margin were calculated on a per-hour basis based on the assumptions in each model. The total daily gross profit margin was also calculated for each business.

Why Hourly Unit Economics? Why Daily Gross Margin?

Revenue, operational expenses, and gross profit margin were calculated on a per-hour basis in order to create a metric that could be used to compare the financial performance of each business. Although knowing the gross margin made on a ton of pulped coffee might be useful to a savvy coffee entrepreneur, we thought it was less helpful to the average reader than knowing what someone could earn from an hour of their work.

Daily gross profit margin was also estimated and is a more insightful way to compare the earning potential of the different businesses. From a customer perspective looking to invest in a business, they are interested in knowing how much they would earn per day, which is a function of both the hourly earning potential and the hours of operation.

Calculating CAPEX Costs

Each model includes an assumption of the CAPEX costs and capitalization period in order to calculate the depreciation of the equipment.

We found a large variation in product prices provided by suppliers. In some instances, the products we modeled are still in development and there is no clear price. For this reason, all CAPEX costs are intended to be representative but do not reflect a single supplier's quote.

Equipment lifespan is also a subject of potential debate. Although many machines are expected to have up to a 10-year lifespan, we expect that consumers do not evaluate their investment opportunities over such long periods and instead look at how they perform in the near future. For this reason, we modeled a 3-year capitalization period for each product: this is the shortest reported lifespan of the products that we evaluated and is often reported as the lifespan of diesel generators, which have CAPEX costs similar to many of the products presented in this research.

Modeling Technologies

A broad overview of available technologies is presented in the background of each section. In the modeling sections, a single technology is selected to be evaluated in each business model. This raises the question: how would the business change if a different technology was used?

In most cases, we modeled and evaluated more technologies than what is presented in the paper. From these, we presented what we believe to be the best case scenario. In a few instances, we chose to model more than one technology if the choice of technology had significant impact on the outcome and was non-obvious.

Modeling Businesses

To conduct this research, it was essential that we collect reliable information from numerous stakeholders such as local technology distributors, farmers, and business owners.

The data that we collected from interviews went through a soft fact-checking process: we compared data from multiple sources against each other, against literature research, and against our team's internal experience with the topic. When we found inconsistencies, we collected additional information until we had a reasonable understanding of what caused the inconsistency and what could be expected in a typical use-case.

Judgement calls are necessary in the modeling process: we are not reporting on a single existing business case, but constructing a representation of a business based on multiple sources. Although this can be seen as a potential weakness of the approach (the model is only as good as the authors' credibility), it also allows potentially misleading data points to be treated separately.

Modeling the Costs of Solar Energy

A key parameter in each of our models was the cost of solar energy. We modeled the cost of electricity across three discrete tariffs:

> <u>Conservative – $1.00 per kilowatt-hour</u>: A conservative figure representing the upper bound of tariffs. This was based on a 2018 paper by Rocky Mountain Institute that found that mini-grid prices ranged from $0.60 to $1.00 per kilowatt-hour[1].
>
> <u>Base – $0.60 per kilowatt-hour</u>: A tariff that represents the middle-ground for well-run mini-grids. This was based on the lower bound presented in the Rocky Mountain Institute paper. We chose to use this as our base case because most mini-grid sites charge favorable rates for productive-use appliances.
>
> <u>Ideal – $0.40 per kilowatt-hour</u>: A tariff that represents the present day cost of solar electricity under ideal circumstances. This was based on a paper by Lee and Callaway, 2018, which found that most regions in Africa can achieve 95% energy reliability using solar at a cost of $0.40 per kilowatt-hour[2].

Seasonality and load profiles are often important considerations when dimensioning solar systems, as irregular usage patterns result in an excess of unused energy and increase the effective cost of electricity. Under a tariff approach, these factors are implicitly included in the tariff.

An early version of this paper modeled products being used on stand-alone systems and included considerations for how seasonality affected the cost of energy; however, that modeling approach was removed in this version of the paper as it ultimately did not affect outcome of the productive-use evaluations.

Approach to Analysis of Productive-Use Cases

Evaluation Framework: Desirability, Feasibility, and Viability

We framed our research and its conclusions along the lines of a Desirability-Feasibility-Viability (DFV) framework. In a DFV approach, we must satisfy customer, technical, and business requirements to successfully scale a product concept; a breakdown on any axis results in a failed product.

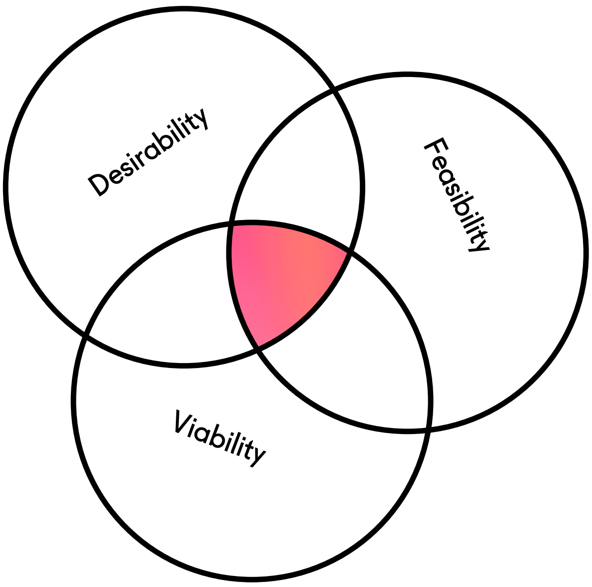
- Desirability: Does the product deliver an attractive value proposition to our users and to their customers?
- Feasibility: Does the technology work?
- Viability: Can a business successfully bring this product to market?

This approach manifested itself in the development of the business models for each product and in the subsequent evaluations.

Each model began with addressing the feasibility of the product. Our modeled businesses were based on operation of existing technologies that we believed had high potential to scale based on research. For this reason, all products modeled in this paper are considered feasible.

The desirability of each product was evaluated through the business models and their profitability: a highly profitable product is desirable. Consideration was also made for the desirability of the services that end-users received from the productive-use technologies.

Lastly, the viability of each product was considered through discussion of potential challenges that are associated with scaling of the product. Customer education, financing, and logistics are examples of viability factors that were considered.



Evaluating Desirability

In considering the Desirability of each product, we looked at how the business fulfilled the value proposition for the business owner and the end customer.

For business owners, we considered the following metrics:

- Is the business profitable?
  For this metric, profitability is measured by the unit economics: positive unit economics implies profitability.
- Is the business able to generate more than $8 per day in daily gross profit?
  An $8.00 benchmark was selected as it is a typical daily gross profit margin reported by diesel mill operators.
- Does the business have predictable demand?
  This metric looks at the services provided and whether the demand is stable and predictable (such as the processing of staple crops) or is difficult to predict (such as the sale of supplementary food items).
- Does the user spend less than 33% of their gross profit earnings on CAPEX?
  This metric compares the CAPEX depreciation costs to the gross margin. It represents how much money the business operator must spend on their equipment.

For end-users, we considered the following metric:

- How do the business services compare with alternatives?
  In this metric, we consider how the services provided in the productive-use case compare to alternatives. In each model, we consider the time, labor, cost, and service quality implications.

The evaluation is summarized in the following two tables below, which are included after the calculations in each section.

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	
Gross Margin More Than $8/day	
Predictable Demand	
Capex over Gross Margin < 33%	

DESIRABILITY OF BASE CASE FOR END-USERS	
Time	
Labor	
Costs	
Service Quality	

Evaluating Viability

The viability of each productive-use case was evaluated by identifying potential barriers for the off-grid energy sector to scale the technology. We considered a product viable if it was a turn-key product and did not require extensive customer engagement.
In evaluating viability, we considered:

- Can a user be trained on the product in one day?
  This metric considers the technical complexity of the product. Complex products require additional costs for training and customer support and are more difficult to scale.
- Does the productive-use business require additional functions and skills to be successful, e.g. a marketing function?
  This metric considers how dependent the business case is on the selection of the customer. Products that depend on an operator having special skills in their business reduces the market size and adds complexity to the customer identification and training processes.
- Is the business still Desirable at half capacity?
  This metric considers whether the business still meets the Desirability metrics when run at lower capacity. Products that are only attractive under optimal market conditions are harder to scale, as additional resources must be used to identify suitable markets.

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	Yes

Discussion of Modeling Results

Following the evaluation of Desirability and Viability, a brief discussion of the results is given. This section explains how the product was evaluated and is also used to highlight important considerations in the modeling, such as which variables have a significant impact on results and how the model would respond if certain assumptions were changed.

Conclusions and Productive-Use Verdicts

At the end of each productive-use case, a brief conclusion section summarizes the findings. Additionally, a verdict is given on whether the product has productive-use and should be brought to market or not.

Three verdicts are possible:

- Low Productive-Use Potential
  This verdict is given when there is something fundamentally detrimental to the business case associated with a technology that is considered unlikely to change in any circumstances.
- Conditional Productive-Use Potential
  This verdict is given in cases where only some of our criteria for Desirability and Viability are met but there are plausible circumstances where they product could still be used productively.
- High Productive-Use Potential
  This verdict is given in cases where all of our criteria for Desirability and Viability are met.

A summary of challenges and conditions for success are included in each conclusion section.

ADDITIONAL READING CONSIDERATIONS

How to Interpret and Use Results

To put it informally, the results of our analyses are rough estimates. Our conclusions should be treated as a guide, but not as an exacting one.

We encourage readers to consider the assumptions made in each model and how plausible they are in their own operating environment, and then to input their own data and assumptions into each model. To support readers in forming their own conclusions, we tried to be transparent about our methodology and assumptions, as well as call out important variables for extra consideration.

Painting in Broad Brush Strokes

In planning this research, we wanted our results to be useful to the off-grid industry at large. To achieve this breadth, it was necessary to sacrifice depth. Model variables were reduced to what we deemed essential and complex topics were simplified wherever possible.

Assumptions used in our modeling, such as technology specifications or cost data, were selected to be representative but do not necessarily capture nuances, outliers, or a complete picture.

Geographic Focus: Tanzania

This research was conducted in Tanzania, with the majority of local data collected in the north of Tanzania. The further away from Tanzania you go, the more discrepancies we would expect between our assumptions and what might be find on the ground. Consequently, our conclusions become less relevant the further one is from Tanzania.

Despite this, we believe the results and our conclusions are of practical use to practitioners all over the world. However, to make full use of this report, readers may need to invest time to gather their own data and apply it to the models.

DIY Modeling: Using Your Own Local Data

All spreadsheets used in calculations for this research are available for download on the A2EI website. Users can download these and input their own data and see how this affects the results. Users can also easily edit these to include their own variables.

To download the datasheets, visit https://a2ei.org/news/productive-use-report.

Feeding Back: Improving the Models

Come up with your own model? Know of contexts where the data is totally different? Have a new technology that out-performs anything here? Got an axe to grind?

We would love to hear from you.

We hope that this paper forms the basis of a conversation that continues far beyond the reaches of our lab. As technology evolves, as businesses innovate, and as we collect data from more parts of the world, we hope to continue to collect and share these new insights so that others may learn.

Comments, questions, and more can be directed to *report@a2ei.org.*

#3 APPLICATION OF THE METHODOLOGY TO TANZANIA: EXECUTIVE SUMMARIES OF 10 TECHNOLOGIES

SUMMARY: OIL EXTRACTION

OVERVIEW OF CURRENT OIL EXTRACTION PROCESSES

Farmers grow oil bearing crops such as sunflower seeds to make cooking oil, which is both consumed in the house and sold. Seeds are brought to on-grid oil expeller machines where they are subjected to high pressure to extract the oil. Farmers often receive free oil pressing services in exchange for the seedcake, which operators sell as animal feed. When farmers take their seedcake, they are charged $0.07 per kilogram of seed processed. A typical on-grid expeller is 20kW and processes 200kg of sunflower seed per hour to make 60L of oil.

USAGE OF SOLAR POWER

Farmers that grow oil-bearing crops can take them to a solar-powered oil extraction business located in their community. They would pay for their seed to be processed and take their oil for home usage and sale.

MODELED BUSINESS

A $2000, 3.75kW oil press on a $0.60/kWh tariff that presses 80kg of seeds per hour, operates 7 hours a day for 50% of the year, charges $0.07 per kg of seed pressed, and serves 100, 2-acre farms growing 900kg of oil seeds.

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$4.31
Daily Gross Profit	$/day	$30.19
CAPEX over Gross Margin	%	6%

CHALLENGES

- Slower throughput: farmers that sell their oil may prefer to do bulk processing on-grid
- Might require complementary filtration services

VERDICT: <u>High Potential</u>: Broadly applicable technology with high returns

CONDITIONS FOR SUCCESS

- Use of technology employing hydraulic systems

SUMMARY: MAIZE SHELLING

OVERVIEW OF CURRENT MAIZE SHELLING PRACTICES

Smallholders typically shell maize by hand or pay for services. $0.40 is charged to shell a 90 kilogram sack of maize, which takes 3 hours to shell by hand. Shelling happens during the brief post-harvest period and farmers typically harvest 1 – 2 tons of maize per acre. Mechanized maize shelling services are offered in some areas, where petrol engine-driven shellers are brought to farms to process the entire harvest.

USAGE OF SOLAR POWER

Solar-power enables products such as small-scale maize shellers to be operated in off-grid areas close to farmers. With this business, farmers bring their maize to the sheller and pay for it to be processed.

MODELED BUSINESS

A $150, 0.5kW maize sheller on a $0.60/kWh tariff that shells 180kg of maize per hour, operates 8 hours per day for 2 months each year, and charges $0.44 per 90kg shelled.

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$0.58
Daily Gross Profit	$/day	$4.64
CAPEX over Gross Margin	%	18%

CHALLENGES

- Low gross margin per day, especially relative to engine-driven alternatives
- Faster and more convenient alternative services available for smallholders
- Difficult to find environments where business is profitable

VERDICT: <u>Low Potential</u>: Complicated by transport and faces lots of competition

SUMMARY: SPICE GRINDING

OVERVIEW OF CURRENT SPICE GRINDING PRACTICES

Farmers that grow spices in Tanzania typically sell their harvests in bulk to traders and middlemen who bring the raw material to on-grid facilities for processing. A typical on-grid grinding machine is a 15kW hammer mill that can process 250 kilograms per hour at a $0.20 per kilogram charge.

USAGE OF SOLAR POWER

Solar power enables off-grid processing facilities to be established so farmers can grind their spices before sale.

MODELED BUSINESS

A $500, 1.5kW hammer mill on a $0.60/kWh tariff that grinds 20kg of spices per hour for 8 hours a day for 25% of the year and charges $0.20 per kilogram of spices ground.

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$3.50
Daily Gross Profit	$/day	$28.00
CAPEX over Gross Margin	%	7%

CHALLENGES

- Unreliable demand for services
- Farmers find it challenging to find a market for ground spices and express preferences to sell in bulk
- Established supply chain that is becomes less efficient if processing moves off-grid

VERDICT: Conditional Potential: Can be profitable but not well suited to Tanzanian spice market

CONDITIONS FOR SUCCESS

- Farmers have easily identifiable market for ground spices

SUMMARY: RICE HULLING

OVERVIEW OF CURRENT RICE HULLING PROCESSES

Rice farmers collect rice paddy in bags after harvest and sell most of it to traders. Their remaining harvest is stored and brought throughout the year to on-grid mills for hulling, polishing, and cleaning so that it can be consumed in the house. Farmers pay $1.51 per 90kg of rice.

USAGE OF SOLAR POWER

Small-scale solar powered rice mills can provide services to off-grid rice farmers, who can bring small amounts of rice paddy to the hulling machine for processing into brown rice that they can consume at home.

MODELED BUSINESS

A $500, 375W rice huller on a $0.60/kWh tariff that processes 75kg of paddy per hour, charges $1.51 per 90kg, and operates for 1.4 hours each day for the entire year to serve 100 households consuming 7.5kg of rice per week

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$1.03
Daily Gross Profit	$/day	$1.45
CAPEX over Gross Margin	%	32%

CHALLENGES

- Low income-earning potential that is capped by surrounding population
- Challenges identifying sites where the business can be very successful

VERDICT: Conditional Potential: Requires sizable population that depend on services

CONDITIONS FOR SUCCESS

- Areas with high population of off-grid rice farmers that are far from on-grid rice mills

SUMMARY: FRUIT JUICE MAKING

OVERVIEW OF CURRENT FRUIT JUICE BUSINESSES AND CONSUMPTION

In on-grid areas, entrepreneurs (who are typically women) will blend fresh fruit into juice using kitchen blenders and sell it throughout offices, residential areas, and marketplaces. Fresh fruit juice can be difficult to find off-grid, where people instead consume fresh fruit or packaged drinks.

USAGE OF SOLAR POWER

Solar power enables kitchen blenders to be operated off-grid and used to make juice

MODELED BUSINESS

A $30, 350W juice blender on a $0.60/kWh tariff that can blend 1L of juice in 2 minutes and makes 10L of juice per day that is sold in half liter cups for $0.22 per cup

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$6.47
Daily Gross Profit	$/day	$2.16
CAPEX over Gross Margin	%	1%

CHALLENGES

- Low-income business that is capped by number of customers
- Non-essential good with hard to predict demand
- Difficult to identify target customers or areas

VERDICT: Conditional Potential: Difficult to depend on customer base

CONDITIONS FOR SUCCESS

- Used in high traffic area and/or used as supplementary income stream for complementary business

SUMMARY: SUGARCANE JUICING

OVERVIEW OF CURRENT SUGARCANE JUICE EXTRACTION AND CONSUMPTION

Sugarcane juice is made by passing sugarcane between metal rolls that compress the cane to extract juice. Manual juice making machines are still used and sometimes retrofitted with motors; modern sugarcane juicing machines achieve the same result with better efficiency. The juice is often flavored with ginger and lemon, and the cane can also be bought and chewed in its raw form.

USAGE OF SOLAR POWER

Solar power enables powered sugarcane juicing machines to be used in off-grid areas for business

MODELED BUSINESS

A $650, 375W sugarcane juicing machine on a $0.60/kWh tariff that can process 60L per hour and makes 10L of juice per day that is sold in half liter cups for $0.22 per cup

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$17.30
Daily Gross Profit	$/day	$2.88
CAPEX over Gross Margin	%	21%

CHALLENGES

- Low-income business that is capped by number of customers
- Non-essential good
- Difficult to identify target customers or areas

VERDICT: Conditional Potential: Difficult to depend on customer base

CONDITIONS FOR SUCCESS

- Used in high traffic area and/or used as supplementary income stream for complementary business

SUMMARY: FRUIT DRYING

OVERVIEW OF CURRENT FRUIT DRYING PRACTICES

A large amount of fruit is underutilized each year due to the seasonal glut of supply. Passive food dryers that convert sunlight into heat are used by cooperatives and small businesses to make dried fruit and other products that are sold to high end markets such as chain grocery stores and international markets.

USAGE OF SOLAR POWER

Solar electricity can be used to power electric food dryers that dry fruit for sale to high end markets

MODELED BUSINESS

A $400, 600W food dehydrator on a $0.60/kWh tariff that runs on a 50% duty cycle and has 1.4 m^2 of drying capacity and dries a full load of 8.4kg of mango over 11 hours and sells the dried product at $17.66 per kilogram

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$2.03
Daily Gross Profit	$/day	$22.38
CAPEX over Gross Margin	%	2%

CHALLENGES

- Profitability depends on ability to sell into high value market
- Customers need training on sales and marketing
- Only minimal advantages over passive driers, may not be preferred

VERDICT: Conditional Potential: Business success is a function of marketing skills, not technology

CONDITIONS FOR SUCCESS

- Operator can create valuable sales channels

SUMMARY: MAIZE FLOUR MILLING

OVERVIEW OF CURRENT MAIZE FLOUR MILLING PRACTICES

Off-grid farmers can walk up to 10km carrying 10 – 20kg of maize to have it milled at a diesel powered mill. Diesel mills process upwards of 120 kilograms of flour per hour and offer complementary degerminating services to improve the flour quality. Customers typically pay $0.04 per kilogram of flour milled and an average household consumes 7.5 kilograms of maize flour per week.

USAGE OF SOLAR POWER

Solar power enables new mills to be established in off-grid areas and serve the nearby local population.

MODELED BUSINESS

A $1000, 4.4kW system that runs a 2.2kW flour mill and 2.2kW hulling machine on a $0.60/kWh tariff and processes 90kg per hour, charges $0.065 per kilogram, and is used year round to serve 100 nearby households

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$3.11
Daily Gross Profit	$/day	$3.74
CAPEX over Gross Margin	%	33%

CHALLENGES

- Needs large population as each household has fixed earning potential
- High power consumption makes business sensitive to tariff
- Can be difficult to identify target areas due to competition

VERDICT: Conditional Potential: Requires effort to identify the right market and customer

CONDITIONS FOR SUCCESS

- Areas with numerous maize growing households and low presence of other types of mill

SUMMARY: PEANUT SHELLING

OVERVIEW OF CURRENT PEANUT SHELLING PRACTICES

Peanut farmers often depend on manual shelling processes. Hand shelling is extremely slow and can take a full hour just to shell 1 kilogram of peanut. Meanwhile, locally made low-cost shellers have mixed results and lower the nut quality. Farmers typically harvest 120kg of shelled nuts per acre and pay $0.065 per kilogram shelled.

USAGE OF SOLAR POWER

Solar power can enable low-power, mechanized shellers to be operated in remote areas and decrease manual labor for farmers.

MODELED BUSINESS

A $600, 375W peanut sheller on a $0.60/kWh tariff that can produce 110kg of shelled peanuts per hour, charges $0.065 per kilogram, and operates 7.2 hours per day for 3 months each year to serve 100, 2-acre farmers

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$6.93
Daily Gross Profit	$/day	$49.86
CAPEX over Gross Margin	%	4%

CHALLENGES

- Supply chain for small-scale models not well developed

VERDICT: High Potential: Profitable business that uses low power and can be successful in remote areas

SUMMARY: COFFEE PULPING

OVERVIEW OF CURRENT COFFEE PULPING PRACTICES

After coffee cherries are picked they are split open to remove the coffee bean in a process called pulping. Farmers typically use manual, hand-cranked pulping machines if they are not in a cooperative. Farmers can choose to hire laborers to perform the services and pay them $0.043 per 15k of cherries pulped, which takes 10 minutes by hand. Farmers can harvest more than 1 ton of coffee cherries per acre.

USAGE OF SOLAR POWER

Solar power enables powered coffee pulping machines to be operated as a service business. Farmers can bring their coffee cherries to a processing point and pay to have them pulped before bringing them back to the farm.

MODELED BUSINESS

A $500, 750W coffee pulping machine on a $0.60/kWh tariff that can pulp 1200kg of cherries per hour, charges $0.043 per 15kg, and operates 1.1 hours per day for 50% of the year.

Metric	*Unit*	*Value on Base Tariff*
Hourly Gross Profit	$/h	$2.99
Daily Gross Profit	$/day	$3.29
CAPEX over Gross Margin	%	28%

CHALLENGES

- Huge volume of coffee necessary to reach capacity
- Transport of coffee cherries is difficult and potentially costs more than services provided
- Hiring laborers is convenient and low-cost service

VERDICT: Low Potential: Transport issues make the business model unattractive for customers

#4 APPLICATION OF THE METHODOLOGY TO TANZANIA: ASSESSMENT OF 10 TECHNOLOGIES

OIL EXTRACTION

Introduction

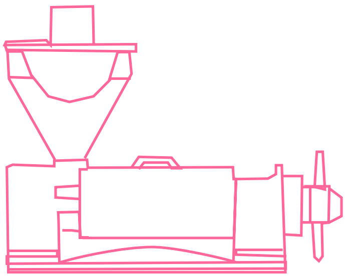
Oil-bearing crops such as sunflower, avocado, moringa, peanut, and sesame are commonly grown across Tanzania. Oil extraction machines are used to extract oil from crops for applications such as cooking and cosmetics.

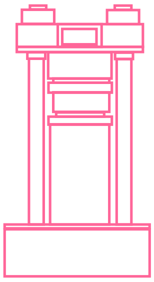
Overview of Technology

Oil extraction machines exert high amounts of pressure on oil-bearing crops until the oil is separated from the rest of the biomass. Raw oil often undergoes separate refinement and filtration processes to remove impurities.

Oil expellers are the most common extraction machine used in Tanzania. Expellers have a screw that turns in a sleeve that continuously moves material forward as it rotates, resulting in increased pressure at the end and heat from friction. Larger machines ranging from 15kW and above are often used for sunflower, but small-scale hand-operated expellers can be found in use with moringa.

Oil presses are one of the simplest forms of oil extraction machines. Crops can be placed within a container of the press that is held under pressure until the oil passes through small outlets. Presses often use hydraulic systems to generate pressure, but non-hydraulic designs such as ram presses and screw presses are commonly found in small-scale manual design as they are easier to manufacture. Presses cannot be continuously operated, as the biomass must be removed after each pressing action and the pressed material is often held under pressure for some time. This results in periods of each pressing cycle wherein the machine is not actually powered.





TECHNOLOGY OVERVIEW			
Model	Small-Scale Hydraulic Press	Small-Scale Expeller	Large-Scale Expeller
Typical Power	1 - 5 kW	1.5 - 3 kW	15 - 20 kW
Throughput	15 - 75 kg/h	5 - 35 kg/h	~ 200 kg/h
Advantages	Powered for only brief periods Simple fabrication Cold-pressed	Continuous extraction	High throughput
Disadvantages	Batch processing	High energy consumption Requires precise fabrication	Energy Intensive Generates heat

Productive-Use Case Analysis: Oil Expelling

In the following section, we model two hypothetical businesses providing oil pressing services to off-grid areas. One business uses a small-scale expeller, and another uses a hydraulic press.

Limitations of Modeling

Oil extraction is affected by numerous variables, some of which are not explicitly included in our model. Instead, many of these variables are implied in the dependent variables that we use.

Looking at the input materials, the crop type (e.g. sunflower vs. sesame), crop strain, moisture content, and pre-extraction processing (e.g. hulled vs. dehulled sunflower) can each influence the performance.

Further, the specifics of the extraction technology are also important. The motor selection, hydraulic pump selection, hydraulic system configuration, machine dimensions, operating parameters (e.g. holding time and holding pressure), and the addition or removal of heat can all affect performance.

Our market and business assumptions will also affect results, such as the local price of animal feed, crop prevalence, local connections to market, presence of other competing extraction units, and other factors.

Variables that were determined to likely influence results in a significant way were either included in our analysis or else noted in the discussion of results.

Model: Oil Extraction Business Using Small-Scale Expeller

JOBS TO BE DONE	
Operator	Generate income
Farmer	Press seed into oil with minimal labor, time, and cost

Original Business Scenario

Farmers that grow oil-bearing crops take them to on-grid areas after harvest to have them pressed into oil, which they use for cooking and also to sell. They patron businesses that have large-scale oil expellers that can process 200 kg/h of seed and also offer filtration services. Farmers report harvesting approximately 450 kg of oil seeds per acre, which they can press for 130L of oil.

New Business Scenario

Farmers that grow oil-bearing crops can take them to the new solar-powered oil extraction business, which is located in their community. They pay for the oil extraction and collect the oil in buckets to take home.

Technology Inputs and Assumptions

For our technology, we modeled a press based off of specifications of a small-scale expeller presented in Callahan et al in Small-Scale Oil Oilseed Presses[3]. The throughput is measured by the amount of input that can be processed per hour, rather than the output.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$2000
Capitalization Period	years	3
Power	kW	2.2
Throughput	kg/h	28

Although the CAPEX costs for the expellers presented in Callahan et al range from $6,000 to $15,000. We chose to model a much lower CAPEX cost of $2,000 based on the positioning of the product with larger-scale expellers priced in the $3,000 – $5,000 range. We believe the prices quoted in literature are representative of the niche market that small-scale expellers are marketed to and would be reduced through economies of scale if a larger market was present.

Business Inputs and Assumptions

To model our business, we interviewed operators of large-scale sunflower oil expellers operating in the Meru region of Kilimanjaro. Many operators offer oil pressing services for free but keep the seed cake (reported to be roughly 70% of the mass of the seed), which can be used in animal feed mixes or sold raw for animal feed. If the customer chooses to keep their seed cake, most operators charge them 150 TZS ($0.065 USD) per kg of seed.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Price per Seed	$/kg	$0.065
Daily Usage	h/day	8
Seasonal Utilization	%	50%

The utilization of the press is expected to be seasonal and interviewees reported their businesses were active roughly 50% of the year, during which they were operated consistently for the entire day. The expeller was modeled to be at full capacity and an 8-hour day was used.

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$1.82	$1.82	$1.82
Hourly Operating Expenses	$/h	$2.20	$1.32	$0.88
Hourly Gross Profit	$/h	($0.38)	$0.50	$0.94
Daily Gross Profit	$/day	($3.04)	$4.00	$7.52
CAPEX over Gross Margin	%	(%120)	91%	49%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	Yes
Capex over Gross Margin < 33%	No

DESIRABILITY OF BASE CASE FOR FARMERS	
Time	Increase in service time; Decrease in transport time
Labor	No change
Costs	Decrease in transport costs
Service Quality	No filtration services

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

The desirability of the product is questionable for operators. Although the business is profitable and is offering a service that smallholders consistently use, the daily earning potential is relatively low and a significant amount of the income earned goes toward CAPEX payments despite the fact that we modeled those costs to be lower than literature-reported values.

For farmers growing oil-seed crops, the desirability is unclear: there is a clear benefit to having oil extraction services located closer to them rather than traveling on-grid, but the services are also much slower than those provided on-grid.

The desirability of the services depend partly on how close alternatives are, but also depend on how the farmers intend to use their oil. Farmers consuming oil in the house would likely be okay with slower processing speeds and pressing oil on an as-needed basis, but those processing their oil for sale would likely find it more efficient to process everything on-grid. Filtration services were not included in our modeling, but are potentially significant.

The viability of the product for scaling is questionable due to the difficulty in finding markets where this kind of service is in demand by operators and farmers. Higher power expellers could provide more attractive services and be more desirable but would also create higher risk for operators who would need a big enough market to recoup their investment.

Model: Oil Extraction Business Using Hydraulic Press

Technology Inputs and Assumptions

To model our hydraulic press, we collected information from a hydraulic press being used to press dried avocado for oil in western Tanzania.

The press holds 5 kg of dried avocado and can press a batch in four minutes. Most of this time is spent loading and unloading the press and holding it under pressure, during which the motor is not required to be on. In the four-minute cycle, one minute is used to extend and retract the 3.75kW motor, representing a duty cycle of 25%.

Hydraulic oil presses are difficult to source, so we created a rough estimate of the CAPEX costs based on components and added a 100% margin. CAPEX costs were conservatively estimated at $2,000.00.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$2000
Capitalization Period	Years	3
Power	kW	3.75
Loading Capacity	kg/batch	5
Batch Cycle Time	s/batch	240
Batch Press and Release Time	s/batch	60
Batches per Hour	batch/h	15
Duty Cycle	%	25%

Business Inputs and Assumptions

For our business, we assume similar service charges as with sunflower. Although, the market price for pressed avocado cake is higher than for sunflower seed cake, we chose to keep the per kilogram rates equivalent so as to focus on the technology.

For our usage, we assumed a 7-hour work day and 50% seasonal utilization, which would be sufficient to process crops grown by 100 farmers with 2 acres each and a 900kg annual production.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Price per Dried Avocado	$/kg	$0.065
Daily Usage	h/day	7
Seasonal Utilization	%	50%

Technical Aside: Pump Selection & Power in Hydraulic Systems

Consider our basic hydraulic press system: a motor turns a pump that displaces fluid and moves a pressing cylinder.

<u>What would happen if we changed our pump to a model that displaced half the fluid?</u>

Each rotation of the pump would move the cylinder half of the distance as the original pump. The cylinder would take two times longer to fully extend.

<u>How would changing the pump affect the power and energy in our system?</u>

Power is energy over time, and energy is always conserved. Thus, the pressing cycle always uses the same amount of energy but smaller pumps require less power because each pressing cycle takes more time.

<u>How does decreasing the pump size affect the throughput?</u>

Decreasing the pump size will lower the throughput but not in a 1-to-1 relationship. Changing the pump only decreases the time spent on the pressing action, but not the time spent holding the biomass under pressure.

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$4.88	$4.88	$4.88
Hourly Operating Expenses	$/h	$0.94	$0.56	$0.38
Hourly Gross Profit	$/h	$3.94	$4.31	$4.50
Daily Gross Profit	$/day	$27.56	$30.19	$31.50
CAPEX over Gross Margin	%	7%	6%	6%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	Yes
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR FARMERS	
Time	Increase in service time; Decrease in transport time
Labor	No change
Costs	Decrease in transport costs
Service Quality	No filtration services, lower temperature extraction

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	Yes

Discussion of Modeling Results

The oil press has strong income-earning potential and is likely a desirable business for operators. Even on a conservative tariff, the unit economics are profitable and the daily earning potential is many times higher than the $8.00 benchmark.

The desirability of the extraction services is less clear: services are more convenient if off-grid but are also twice as slow. We believe the speed would likely be acceptable for extracting oil for household consumption, but farmers pressing oil for commercial usage might prefer alternatives depending on their convenience.

We did not model filtration services and their impact on the business case or desirability, however cold-pressed oils are typically of higher quality than hot-pressed oils and the process would likely produce fewer impurities than expellers due to less friction.

The product and business case is likely viable for scaling due to the simplicity of the technology and the well-understood business model. We believe the market for this kind of product should be relatively easy to find: under the base case, the product can be operated at 25% capacity and still meet our criteria for Desirability, implying that the business can succeed in smaller markets or in areas with competition that reduces the operator's market size.

Conclusions

Under the given assumptions, the hydraulic oil press outperforms the expeller technology and has strong potential to be used productively on solar.

Due to its high loading capacity, the hydraulic press is capable of processing larger volumes per hour and thus generates higher revenue than the expeller. Despite having a higher power motor, the hydraulic press uses less energy due to its non-continuous operating cycle.

The earning potential of the press is significant enough that it generates an attractive level of income even if operated for a fraction of the day. This suggests the product can be used in areas with small populations, as it can be profitable in spite of limited demand for services.

Small-scale pressing technology will require further development before its adoption can be widespread. Despite its simplicity, we found relatively few instances of hydraulic oil presses actually in use, likely due to the preference for high power oil expellers in on-grid applications. In designing this kind of product, developers should consider the interplay of the motor, pump, and pressing chamber on the production capacity and energy consumption. Although our model used a 3.75kW motor, smaller motors could likely be used with this technology without changing the productive-use case.

Verdict

High productive-use potential

Challenges

- Slower throughput: farmers that sell their oil may prefer to do bulk processing on-grid
- Might require complementary filtration services

Conditions for Success

- Use of technology employing hydraulic systems

MAIZE SHELLING

Introduction

Maize is a staple crop for the majority of households in Tanzania, where over 80% is grown on smallholder farms and up to 80% is consumed within producing households[4]. After harvest, maize kernels are removed from the cobs in a process called shelling before they can be further processed into maize flour. As the majority of small farms rely on manual methods to shell their maize, mechanized shellers present an opportunity for new services.

TECHNOLOGY OVERVIEW			
Model	Manual Maize Sheller	Single-Cob Motorized	Engine-Driven Threshers
Typical Power	Manual	0.5 – 1.5 kW	4 – 6 kW
Throughput	45 – 135 kg/hr	90 – 300 kg/hr	1350 - 2700 kg/hr
Advantages	Can be portable Low cost	Mechanized	Can be portable High throughput
Disadvantages	Laborious Low throughput	Stationary Low throughput	High upfront cost
Notes	Bicycle powered and hand-crank models available	Double-cob models are available, which can improve shelling speed	Typically diesel or petrol powered Often includes second stage for grain cleaning

Overview of Technology

Traditional maize shelling methods typically require beating maize with a stick or peeling kernels off with hands. Both processes are laborious and time consuming, requiring approximately 3 hours to shell a 90 kg sack.

Mechanized maize shellers automate this process: maize is fed into a shelling chamber where raised profiles agitate kernels until they are removed.

At the lower end of mechanization, human-powered maize shellers are available on the market. In one model, maize is fed into a spring-loaded inlet which pushes the maize against a spinning, studded plate that knocks off the maize kernels as it spins.

Small-scale powered shellers imported from abroad are available on the local market. Cobs are fed into an inlet and pass through a shelling chamber where rotating bars knock kernels from the cob. The ability of the operator to quickly feed maize into the machine is often the limiting factor on throughput.

Engine-driven threshers, both locally-made and imported, are also available on the local market. Most designs have a large inlet where maize can be poured into a chamber where it is shelled by a rotating drum. Cobs pass through an outlet at the end of the chamber, while the shelled maize falls through a screen and is cleaned by a blower or shake table.

Larger scale shellers, such as tractor-driven shellers, are also possible but are less common. While the general shelling principle remains the same, increased power results in increased throughput as more maize can be shelled at once.

The Cost of Maize Shelling

Maize shelling is one of the lowest value services researched in this paper. Although surprising, we found shelling services to be consistently priced at $0.43 per 90kg across many areas of Tanzania. To perform this labor manually requires three hours of hard work, meaning a full day's labor results in less than $1.50 in income.

In some situations, the labor is done without payment as day laborers and neighbors will occasionally work in exchange for food or alcohol.

Limitations of Modeling

Performance of a maize shelling machine can be affected by many factors, such as the feed rate of the operator, the moisture content of the maize, the maize variety, and the maize size. These considerations were not included in our model, which was based on average use case assumptions.

The following model also excludes considerations for transport in the calculations, however these are discussed in the results.

Productive-Use Case Analysis: Small-Scale Maize Shelling

For our business case, we model the use of a solar-powered single-cob maize sheller being used in a shelling service business.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Remove maize from cobs with minimal labor, time, and cost

Original Business Scenario

Farmers that grow maize typically place their maize in large piles on their farm or household. The maize is left in the sun to dry, which makes the shelling process easier and also reduces opportunities for spoilage. After drying, farmers shell their entire maize harvest. Many smallholders will do the shelling by hand themselves or with their family, but there is also a market for day laborers. In some areas, engine-driven shellers are brought directly to farms and perform the shelling services.

After shelling, the farmers put the maize into sacks for storage. A single acre of maize typically produces 1 – 2 tons of shelled maize, and the unshelled weight that includes the cobs is typically twice as much.

New Business Scenario: Small-Scale Maize Sheller Business

After drying their maize, farmers would arrange transport for their unshelled maize to a central processing location where the solar-powered shelling machine is located. Farmers would pay for their maize harvest to be shelled, and then put it into sacks and transport it back to their household.

Technology Inputs and Assumptions

For our technology, we modeled a single-cob maize sheller based on specifications given for imported models found on the local market and tests done on the product in-house. A discussion of how other technologies fare under solar is considered in the Discussion of Results section. For CAPEX costs, we modeled a $150 price based on the model we bought locally.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	150
Capitalization Period	Years	3
Power	kW	0.5
Throughput	kg/h	180

Business Inputs and Assumptions

To model our business, we interviewed users who paid for maize shelling services. Market rate for maize shelling in Tanzania was typically 1,000 TZS ($0.44) per 90kg sack, regardless if done manually or mechanically.

For our utilization rate, we assumed the maize sheller was operated only during harvest season for two months per year, roughly 17% of the time. During that time, there is a large quantity of maize for shelling, thus an 8-hour operational day was modeled.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Maize per Sack	kg/sack	90
Price per Sack	$/sack	$0.44
Daily Usage	h/day	8
Seasonal Utilization Factor	%	17%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$0.88	$0.88	$0.88
Hourly Operating Expenses	$/h	$0.50	$0.30	$0.20
Hourly Gross Profit	$/h	$0.38	$0.58	$0.68
Daily Gross Profit	$/day	$3.04	$4.64	$5.44
CAPEX over Gross Margin	%	27%	17%	15%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR FARMERS			
	In comparison with..		
Metric	Manually Shelling	Paying Laborers	Engine-Driven Services
Time	Decrease in shelling time Increase in transport time	Decrease in shelling time Increase in transport time	Increase in shelling time Increase in transport time
Labor	Decrease in shelling labor Increase in transport labor	Increase in transport labor	Increase in transport labor
Costs	Increase in shelling costs Increase in transport costs	Increase in transport costs	Increase in transport costs
Service Quality	Cleaner product	No change	Less breakage

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

Our analysis shows that a solar powered small-scale maize sheller is likely not profitable enough to be a desirable business for operators. Although it is income-generating, the daily income earning potential is limited and is potentially unattractive. Considering that engine-driven shellers can earn operators $10 per hour, we expect would-be-operators to spend their money on other investments.

The services of the small-scale solar sheller are potentially un-desirable for smallholders. In comparison with performing the work manually, the solar sheller offers better services, albeit at a cost. If a farmer is willing to pay for shelling services, there are more desirable alternatives that can be used at the farm and eliminate the time, labor, and costs required to transport maize to and from the solar shelling machine.

Small-scale shellers are simple to operate and use as a business. However, finding the target market could be challenging given the competition with other products, the low income-earning potential, and the low profitability.

Conclusions

We find that maize shelling businesses have low productive-use potential. Although it is possible to achieve positive unit economics while using solar, we find the business does not earn enough income to be a very attractive investment for operators. Furthermore, the services offered are potentially unattractive to farmers in comparison with alternatives.

This particular business case is challenging in part due to the low value placed on maize shelling services and the extreme seasonality of the processing. In combination, these factors create a business environment wherein large quantities of material needs to be processed in a short period of time but where moving that material may not be economical.

The business earning potential is limited by the amount of maize that can be shelled during the harvest season. Alternative, higher-power maize shelling technologies similar to engine-driven shellers can increase the earning potential for the operator, but their high throughput speeds only exacerbate the transportation challenges.

Verdict

Low productive-use potential

Challenges

- Low gross margin per day, especially relative to engine-driven alternatives
- Faster and more convenient alternative services available for smallholders
- Difficult to find environments where business is profitable

SPICE GRINDING

Introduction

Although Tanzania's most famous spice trade comes from Zanzibar, spices such as ginger, garlic, and coriander are grown on the mainland and play a role in everyday cooking.

TECHNOLOGY OVERVIEW			
Model	Small Spice Blender Mill	Small Spice Hammer Mill	Large Spice Mills
Typical Power	1.5 – 4 kW	1 – 3 kW	10 – 15 kW
Throughput	2 – 15 kg/hr	10 – 20 kg/hr	150 – 250 kg/hr
Losses	<1%	3 – 5%	3 – 5%
Advantages	Low Power	Simple to manufacture	Simple to Manufacture High throughput
Disadvantages	Heats up; must cool between batches	Difficult to clean Heats up	Difficult to clean Heats up High upfront cost

Overview of Technology

Spice grinding machines (also referred to as spice mills) are similar in functionality to flour grinding machines: through friction, crushing, or shearing mechanisms, a spice mill breaks coarse spices down into fine particles.

In urban areas such as Arusha, the majority of spice sellers mill their spices using AC hammer mills, which have rapidly rotating hammers that break apart spices until they are fine enough to pass through a sieve. A blower assists with maintaining high air flow so that spices can pass continuously through.

Spices can also be ground in small mills similar to the common household blender, where a blade spins at the bottom of a bowl to grind material into powder. Unlike other mill types, this mill cannot be run continuously and smaller versions tend to overheat if operated for too long.

Other spice mill architectures such as plate mills, pin mills, and pounding machines exist on the global market but are not prevalent in Tanzania. Often, mills are selected for specific instead of general spice-grinding, which allows considerations for how a certain mill impacts the quality of the finished product. Heat generated from the milling process is often undesirable as it can decrease the quality of the ground spice. Similarly, the use of mild steel instead of stainless steel in locally made spice mills prevents the finished product from being exported.

Like grain mills, the throughput of each mill depends on the fineness of the final product.

Productive-Use Case Analysis: Small-Scale Spice Grinding

For our business case, we model a solar-powered spice grinding mill that offers ginger grinding services for rural farms.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Generate income from sale of spices

Original Business Scenario

Farmers growing ginger dry it after harvesting. The dried ginger is sold to middlemen and traders who transport the product to urban markets where it is processed and packaged into small quantities for sale. The grinding is done at a 15kW AC hammer mill that grinds 250 kg of spices per hour at a $0.20 per kilogram charge.

New Business Scenario: Off-grid Spice Grinding

In the new model, a solar-powered spice grinding machine is established off-grid. Farmers would pay to grind their own spices and then sell the ground material to traders, middlemen, and directly to consumer at markets.

Technology Inputs and Assumptions

For our technology, we modeled a continuously-operated 1.5kW hammer mill, based on a model being tested and promoted by Selco Foundation in India. We estimated a $500 cost for the grinding machine and a three-year capitalization period.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	500
Capitalization Period	Years	3
Power	kW	1.5
Throughput	kg/h	20

Business Inputs and Assumptions

To model our business, we conducted interviews with spice traders in northern Tanzania, who reported paying between 400 and 500 TZS ($0.17 – $0.22) per kilogram of ground spice. Per interviews with ginger farmers, we assumed a harvest season of 3 months, implying a 25% utilization factor. For our daily usage, we modeled an 8 our operating day so that the spices are processed during the peak season.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Price per Kilogram	$/kg	$0.22
Daily Usage	h/day	8
Seasonal Utilization Factor	%	25%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$4.40	$4.40	$4.40
Hourly Operating Expenses	$/h	$1.50	$0.90	$0.60
Hourly Gross Profit	$/h	$2.90	$3.50	$3.80
Daily Gross Profit	$/day	$23.20	$28.00	$30.40
CAPEX over Gross Margin	%	8%	7%	6%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	Yes
Predictable Demand	No
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR FARMERS	
Time	Increased time spent grinding
Labor	Increased labor spent finding a market
Costs	Increase in money spent on spice grinding, increase in income
Service Quality	No change

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	Yes

Limitations of Modeling

This research does not delve into the distinctions between individual spices, some of which do not require grinding at all. Throughput, service prices, and other assumptions may not hold for all spices.

The energy required to grind spices is also influenced by the moisture content of the spices and the desired fineness of the end-product. These variables are excluded for simplicity.

Discussion of Modeling Results

The spice grinding business is financially attractive for operators who can find a market for their services. However, farmers in Tanzania do not typically grind their spices themselves and so the demand for the services in uncertain and the business may not be desirable.

If farmers chose to grind their spices themselves, they add value and can sell it at a higher price. But farmers that choose to process their spices will face the challenge of finding a market for their goods. Middlemen and traders do not face challenges related to spice grinding and have little incentive to pay farmers extra for the processed goods. Farmers that choose to sell their products themselves might find it easier to also process the spices on-grid.

Farmers that were interviewed as part of this research reaffirmed their preference for selling unground spices: for them, the additional processing adds more challenges than value.

Conclusions

Although solar-powered spice milling has potential to be financially attractive for equipment operators, its success requires the spice growers to find a market for their products. In Tanzania there is no easily accessible market for farmers to sell ground spices and so they prefer the existing value chain.

In environments where there is significant household spice production and ground spice consumption, off-grid spice grinding services will be more in demand and this productive-use case can be viable.

During our research we did find a small-scale, solar powered spice-grinding machine in Tanzania being used to grind moringa leaves, a high-value super-food crop. Examples such as this one are usually exceptional: in this case, the technology was owned and operated by a NGO that handled all of marketing for the ground moringa product.

The types of spices, required volumes, market prices for ground and unground spices, and seasonality should be considered before utilizing this kind of technology for a business.

Verdict

Conditional productive-use potential

Challenges

- Unreliable demand for services from farmers
- Farmers find it challenging to find a market and express preferences to sell in bulk
- Established supply chain that is becomes less efficient if processing moves off-grid

Conditions for Success

- Farmers have easily identifiable market for ground spices

A Different Take: Solar-Powered Spice Grinding in India

Our modeling suggested that spice grinding businesses are viable on solar when there is significant consumption of ground spices in rural areas. While the technology is unlikely to scale in Tanzania, we know of at least one market where it is well-suited: India.

Unlike Tanzania where spices are often grown as a cash-crop, many rural Indian households grow spices for their personal consumption. This creates sustained decentralized demand for spice grinding services and allows these small businesses to operate profitably, even on solar.

Selco Foundation, an India-based NGO focused on sustainable innovations, is one of the major proponents of solar-powered spice mills. Through their work on livelihood development, Selco Foundation has developed and adapted multiple solar-powered spice mills and business models for local markets.

One of the other business models their users implement is blending spices into curry powders for sale in larger domestic markets. In one instance, a user operated a small-scale mill that was backed up with solar power, allowing it to operate uninterrupted.

Understanding local context is critical to making conclusions.

RICE HULLING

Introduction

Rice is a staple crop of Tanzania and the third most cultivated food and commercial crop after maize and cassava[5]. In this section, we look at rice hulling, one of the primary steps in the rice milling process.

Overview of Technology

Rice hulling is one step of rice milling in which the husk of the rice is removed from the grain, resulting in brown rice. The process is typically done by running rice between abrasive rolls. Other milling processes typically follow hulling, such as polishing the hulled grain to remove the outer bran layers resulting in white rice. A machine that does multiple stages of the process is typically called a mill rather than a huller.

Most rice in Tanzania is processed using on-grid mills, which can resemble small processing plants at the larger end of the spectrum. These mills process large volumes of rice at a time using AC motors ranging up to 30kW and often involve multiple stages that can each require its own motor.

Small-scale rice hulling machinery is uncommon in Tanzania. Instead, small-scale processing is often done using maize peeling machines with different screens, which can damage the grain. On the global market, small-scale rice hullers and mills are available.

The hulling process is seasonal in Tanzania, typically spanning 5 months. During the off-season, rice hulling services can become unavailable as large-scale mills are impractical for processing small quantities.

Resulting grain quality can be impacted by the choice of mill: effective multi-stage mills will result in clean, unbroken grain, whereas a poorly made single-stage mill could result in unclean rice and lower prices.

TECHNOLOGY OVERVIEW			
Model	Small-Scale Rice Huller	Two-Stage Rice Mill	Mini-Rice Milling Plant
Typical Power	375W	20 – 25 kW	30+ kW
Throughput	70 – 80 kg/hr	450 – 540 kg/hr	720 – 900 kg/hr
Advantages	Low power	High throughput Hulls and Polishes	Completely mills rice High throughput
Disadvantages	Only hulls, no polishing	Does not grade rice	Expensive Requires multiple motors

Limitations of Modeling

Our model assumes that there is a market for rice hulling without polishing (i.e. brown rice). Although many prefer to eat white rice, we did find rice hullers in use, particularly in rural areas where it is being consumed within the household. The polishing step added an additional 1,000 TZS ($0.43) to the service price per sack, and represents an opportunity for more value addition.

Productive-Use Case Analysis: Small-Scale Rice Hulling

For this technology, we modeled the use of a small-scale rice hulling machine powered by solar that is operated off-grid as a service business for farmers growing rice for household consumption.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Remove outer bran layer of rice with minimal labor, time, and cost

Original Business Scenario

After threshing their crop, rice farmers collect their rice paddy in bags. Many farmers will sell a portion of their crops immediately after harvest to traders who collect the paddy and bring it to on-grid mills to remove the hull and bran. The unsold harvest is stored in bags and used for household consumption as well as sold intermittently throughout the year when prices increase. Although traditional milling using a pestle and mortar is an option, many farmers choose to bring their paddy to on-grid mills to have it hulled and polished.

New Business Scenario: Off-grid Spice Grinding

The introduction of a solar-powered mill in an off-grid area would enable farmers to hull their rice nearby. Farmers would sell most of their paddy to traders, but would bring small amounts of paddy used for household consumption to the huller for processing throughout the year.

Technology Inputs and Assumptions

For the hulling machine, we modeled a small-scale rice huller based on a 375W rice hulling machine that uses rubber rolls to remove the husk from the paddy. Although the throughput varies based on rice variety, we assumed a 75 kg/hr throughput. A $500 CAPEX cost and 3-year lifespan were assumed.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	500
Capitalization Period	Years	3
Power	W	375
Throughput	kg/h	75

Business Inputs and Assumptions

For our business, we interviewed rice farmers to determine the market rate for rice hulling services, which are 3,500 TZS ($1.51) per 90 kg sack of rice. For the utilization rate, we assumed a 100% utilization rate: although there are peak harvest periods for rice, rice grown for household consumption could be hulled on an as-needed basis.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Rice per sack	kg/sack	90
Price per sack	$/kg	$1.51
Daily Usage	h/day	1.4
Seasonal Utilization Factor	%	100%

Literature research suggests rural farmers reserve 370kg of rice for household consumption. Building off this assumption, we modeled a scenario where 100 households each use the mill and consume 7.5kg or rice per week, resulting in an approximate 1.4 hours of daily usage throughout the year[5].

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$1.26	$1.26	$1.26
Hourly Operating Expenses	$/h	$0.38	$0.23	$0.15
Hourly Gross Profit	$/h	$0.88	$1.03	$1.11
Daily Gross Profit	$/day	$1.24	$1.45	$1.55
CAPEX over Gross Margin	%	37%	32%	29%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR FARMERS	
Time	Decreased time travel, increased time hulling
Labor	No change
Costs	Decrease in money spent on transport
Service Quality	No grading or polishing

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

The low power consumption and high service charge of the huller enables an operator to achieve positive unit economics under the assumed conditions. However, the total earning potential is expected to be limited by the local market size for rice hulling services and the business may not be desirable to operate in areas that are not densely populated.

Households interviewed often hull their rice in 15 kg buckets, which would take 12 minutes in our modeled scenario. Although this is nearly twice as slow as the smallest-scale huller that we found in our field research, we believe the service time would be acceptable.

It is possible that mill operators could make their business more attractive by charging more for hulling services. In addition to charging a premium for convenience if located in an otherwise remote area, operators could increase their prices for smaller batches. Many larger hulling machines will not work for small quantities, and small-scale operators often charge 1000 TZS ($0.43) to hull a 15 kg bucket, almost double the rate charged for larger quantities.

Conclusions

We find that small-scale rice hulling is likely profitable when solar-powered but may not be an attractive business investment unless located in rural areas with large numbers of off-grid rice farmers. As a productive-use product, a rice huller has potential but may not be suitable in many areas.

The profitability of the technology can potentially be improved beyond what is modeled by increasing the service prices, which other small-scale hullers have done in Tanzania.

The earning potential for this business could potentially be expanded by offering additional services, particularly polishing. However, the earning potential is ultimately capped by the quantity of rice consumed locally.

Verdict

Conditional productive-use potential

Challenges

- Low income-earning potential that is capped by surrounding population
- Challenges identifying sites where the business can be very successful

Conditions for Success

- Areas with high population of off-grid rice farmers that are far from on-grid rice mills

FRUIT JUICE MAKING

Introduction

Juice making is a small business opportunity that can be started with just a small amount of upfront capital. Many fruit juice businesses are run by women entrepreneurs who employ a wide range of business models to capture their local market.

Background: Juice Making Models

There are several primary juice-making models that we commonly see in Arusha. Two main ones are a "bulk juice" model wherein an entrepreneur makes a large quantity of a single type of juice before looking for customers, and a "made-to-order" model where entrepreneurs take orders for any juice type and then purchase the ingredients necessary to fulfill the order. In Arusha, we typically find mango and avocado juice made in bulk and that these juices sell for less than the made-to-order blends.

We see these models employed by both stationary vendors working out of permanent locations and roaming vendors who tend to work regular routes. Often the stationary vendors attach themselves to other food businesses such as restaurants or bars.

Overview of Technology

Making fruit juice requires only a blender, fruit, and cups. Access to cold chain (either a refrigerator, freezer, or ice machine) can be beneficial, but is not strictly necessary.

Common household blenders are typically used by local entrepreneurs. These AC-powered blenders are locally available and typically consume less than 500W of power. Users reported their blenders typically lasted 3 years before they needed to be replaced.

TECHNOLOGY OVERVIEW	
Model	Kitchen Blender
Typical Power	375 W
Capacity	1 L
Advantages	Low Cost Available Locally
Disadvantages	Usually AC

Limitations of Modeling

From user interviews, we learned temperature has a large impact on juice consumption. Both juice businesses reported users had a preference for cold juice and preferred to drink it only on warm days. On cold days, they reported their sales would be cut in half. This demand fluctuation was excluded from the analysis to present a best-case scenario.

To chill juice, both used refrigerators. The cost of refrigeration was excluded from our calculations, but is discussed in the results.

Productive-Use Case Analysis: Juice Making Using Solar

For this technology, we modeled a generic bulk juice-making business operating in an off-grid area that makes juice using a blender powered by solar.

JOBS TO BE DONE	
Operator	Generate income
Customer	Enjoy consumption of food and beverages

Original Business Scenario

Small shops and restaurants typically sell packaged beverages such as soda, water, alcohol, and juices. An off-grid consumer looking for a fresher taste might opt for one of those beverages or fresh fruit instead.

New Business Scenario: Juice Sales

An entrepreneur uses a kitchen blender to make 20L of juice in the late morning using fresh fruits bought from neighbors and a blender powered by solar. The juice is stored in plastic jugs and in the afternoon the entrepreneur walks to the local market and looks for customers. Juice is served in glasses that are washed afterwards.

Technology Inputs and Assumptions

For the technology, we modeled a 1-liter kitchen blender that local entrepreneurs in Arusha used for their businesses. Based on interviews, we assumed a 2-minute time to blend each batch, equating to a 30 L/hr throughput. A $30 CAPEX price and 3-year lifespan were used in the model based on user reports and a survey of local shops.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	30
Capitalization Period	Years	3
Power	W	350
Throughput	L/h	30

Business Inputs and Assumptions

To model our business, we conducted interviews with juice makers who reported selling juice in 500 ml cups for 500 TZS ($0.22) each. On an average day, they sell 20 cups of juice and spend 5000 TZS ($2.20) on inputs consisting of fruit, cups, and ice.

Although the fruit season is seasonal, we assumed a steady year-round supply of fruit and thus a 100% utilization rate. Based on the reported sales volumes, we calculated the blender was in use just 20 minutes each day.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Juice per cup	L/cup	0.5
Price per cup	$/cup	$0.22
Juice sales per day	Cups	20
Material inputs	$/cup	$0.11
Daily Usage	h/day	0.33
Seasonal Utilization Factor	%	100%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$13.20	$13.20	$13.20
Hourly Operating Expenses	$/h	$6.87	$6.73	$6.66
Hourly Gross Profit	$/h	$6.33	$6.47	$6.54
Daily Gross Profit	$/day	$2.11	$2.16	$2.18
CAPEX over Gross Margin	%	1%	1%	1%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	No
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	No change
Labor	No change
Costs	Spending shifted from other sources or increased
Service Quality	New product available

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

The unit economics of juice selling are reasonable, but the total earning potential was estimated to be low due to the difficulty in selling the product. The business could be profitable, but is potentially not desirable due to its unpredictable demand and low earning potential.

Relative to our gross margin benchmark of $8.00 per day, the income earned from this business is low. Relative to the CAPEX investment however, the take-home is very high. This suggests that this might have appeal to a different profile of customer due to the relatively low financial risk, especially if used to supplement an existing income stream.

The desirability of juice as a product is difficult to predict. An individual's decision to buy can depend on many factors ranging from current disposable income to the weather to what they ate that day. In crowded urban areas, there is a sufficiently large potential customer base that a salesperson could expect to find customers. In rural areas, population density is typically low and it may be difficult to find enough customers.

Unlike many other technologies we researched, the cost of electricity had relatively little contribution to the costs of the product and is likely not a barrier to proliferation of the businesses. The electricity costs only accounted for 2% – 7% of the operating expenses.

The cost of refrigeration was excluded from our analysis but is a potential barrier to scaling of this business. Without access to the cold-chain, there is less demand for juice and fewer potential customers. Although off-grid refrigeration is declining in price, the costs might still be prohibitive.

Conclusions

Our model suggests that small juice making businesses generate relatively low levels of income and are challenging to successfully operate. As a sole income stream, the productive-use case might not be attractive; however, this business could be a decent supplementary income stream.

The primary challenge for an entrepreneur selling juice is finding the market for their product. The on-grid entrepreneurs we interviewed for our research all eventually shut down their businesses because they struggled to find customers, despite marketing their products in populous business and residential urban areas. In sparsely populated rural areas, we expect entrepreneurs to face a more extreme version of this challenge. Positioning this business in a well-traveled location such as at a popular restaurant or in a local market would improve its likelihood of success.

The market for this product aimed at an off-grid, productive-use customer segment is unlikely to be lucrative for product distributors or energy providers, but it could serve as a marketing tool when paired with complementary products such as refrigerators or electric cooking appliances. Given that most juice businesses are women-owned, it also creates social impact by empowering women entrepreneurs and thus could be attractive as a means of creating social impact.

Verdict

Conditional productive-use potential

Challenges

- Low-income business that is capped by number of customers
- Non-essential good with hard to predict demand
- Difficult to identify target customers or areas

Conditions for Success

- Used in high traffic area and/or used as supplementary income stream for complementary business

SUGAR CANE JUICING

Introduction

Like fruit juice, sugarcane juice is a popular refreshment during hot weather. A typical cane juice vendor carries a juicing machine, sugarcane, and cups in a cart and parks on a street corner or sells out of a restaurant.

Aside: Gender in Juice Making

Although there are no formal studies on the topic, our experience is that juice making in Tanzania is typically a gendered-segregated business: women make and sell fruit juice and men make and sell sugarcane juice.

We can only speculate at the reasons behind this. Perhaps it is driven by perceptions of the technology (fruit juice is made with a kitchen appliance) or the earning potential (our analyses suggest lower earning potential for selling fruit juice than sugarcane juice).

One theory is that it is gendered due to the labor involved, as manual sugarcane juicing requires a lot of upper body strength. Among our research team, the only woman-run sugarcane juice business that we had observed had used a motor-driven juice machine.

Whatever the reason, there is a gender component to consider when discussing technology adoption. While our research only gives a starting point for a discussion, practitioners should consider how gender norms are disrupted or perpetuated through technology dissemination.

TECHNOLOGY OVERVIEW			
Model	Manual Sugarcane Juice	Retrofit Sugarcane Juicer	Modern Sugarcane Juicer
Typical Power	Manual	1 – 5 kW	375 – 1kW
Throughput	15 L/hr	15 L/hr	60 L/hr
Advantages	Low Cost Portable	Easy to Use	Easy to Use High Throughput
Disadvantages	Laborious	Needs Power Source Higher Costs	Needs Power Source

Overview of Technology

Most sugarcane juicers in Tanzania consist of three rotating horizontal stainless steel cylinders. The operator feeds in whole sugarcanes which are crushed by the cylinders to extract the juice, which is collected by a spout beneath the cylinders. The process is repeated several times to ensure complete extraction. Both manual and electric versions of the same design available, although the electric versions are retrofit versions of the manual machine but with the addition of a motor.

Modern, non-retrofitted electric models are also available. These models operate under the same principal, but are often lower power as they are purposefully built to be motor-driven.

Most sugarcane juice is made to order and often includes ginger and lemon for extra flavor.

Limitations of Modeling

We did not have sufficient data to model the sales volume that a rural sugarcane vendor could expect to achieve: while many agricultural services have predictable demand based on harvest outputs, juice is a non-essential commodity and there is no reliable data source on the subject.

Productive-Use Case Analysis: Solar Sugarcane Juicing

For this technology, we modeled a sugarcane juicing business operating in an off-grid area without competition.

JOBS TO BE DONE	
Operator	Generate income
Customer	Enjoy consumption of food and beverages

Original Scenario: Raw Sugarcane Consumption

Sugarcane is often sold and consumed raw. After removing the outer peel with a machete, the cane is cut into pieces that are chewed to extract the fresh juice.

New Business Scenario: Sales of Fresh Sugarcane Juice

Solar-power enables the operation of a powered juicing machine. A vendor establishes a sales location at a storefront or near a restaurant and sets up their equipment there. Sugarcane and spices are passed through the juicing machine to extract the juice, which is sold to passing customers.

Technology Inputs and Assumptions

For the technology, we modeled an electric sugarcane juicing machine modeled after a PIO brand 3 roll sugarcane juicing machine. The machine is estimated to produce 60 liters of juice per hour with a 375W motor. We modeled a $650 price point based on online quotes and assumed a 3-year capitalization period.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$650
Capitalization Period	Years	3
Power	W	375
Throughput	L/h	60

Business Inputs and Assumptions

Our business was modeled after existing sugarcane juicing businesses that we interviewed in Arusha. Market rate for sugarcane juice was between 500 – 1000 TZS ($0.22 – $0.43). A single piece of sugarcane costs 500 TZS ($0.22) and can make 5 pieces of juice. Other inputs such as spices and cups were estimated to cost $0.03 per cup.

The utilization factor was estimated at 100%, as sugarcane is typically available year-round. Although urban sugarcane juice vendors reported higher sales volumes than juice vendors (as much as 60 cups per day), we modeled a 20 cup per day volume to have parity between our two juice models.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Juice per cup	L/cup	0.5
Price per cup	$/cup	$0.22
Cost of sugarcane	$/piece	$0.22
Cups per sugarcane	cup/piece	5
Material inputs	$/cup	$0.03
Cups per Day	cups/day	20
Daily Usage	h/day	0.17
Seasonal Utilization Factor	%	100%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$26.40	$26.40	$26.40
Hourly Operating Expenses	$/h	$9.26	$9.11	$9.03
Hourly Gross Profit	$/h	$17.15	$17.30	$17.37
Daily Gross Profit	$/day	$2.86	$2.88	$2.90
CAPEX over Gross Margin	%	21%	21%	21%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	No
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	No change
Labor	Easier to consume than raw form of sugarcane
Costs	Spending shifted from other sources or increased
Service Quality	New product available

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

The business model shows that sugarcane juicing business is profitable unit when powered by off-grid solar, but that the daily income-earning potential is limited by the number of customers and thus may not be a desirable business.

Similar to the case of fruit juicing, the demand for sugarcane juice is difficult to predict. We found sugarcane juice to be in higher demand than fruit juice in on-grid areas but even if this holds as a general trend, the market for this kind of productive-use business needs to be considered on a case-by-case basis.

An operator of an electric sugarcane business will face competition from any manual juice extraction machines already operating in their area. The difficulty of extracting juice by hand might not be enough incentive to get a manual machine operator to upgrade, especially at low sales volumes.

While electricity is not a major cost driver for the technology modeled, it can be a significant cost driver for the retrofitted machines: improperly set-up machines can consume nearly 40x the energy by being 4 times slower and using 10 times more power. Thus equipment selection is critical for a profitable business and efficiency may be difficult to guarantee for locally modified equipment.

Conclusions

Sugarcane juicers demonstrate potential for being productive-use when powered by off-grid solar if positioned in an appropriate market and operated using an efficient technology, but the business might not be financially attractive for operators who face an uncertain market for their product.

Ideal markets would have hot climates, access to sugarcane, and locations where large numbers of people visit such as marketplaces to ensure sufficient demand for the juice.

Manual juicing machines retrofitted to be motor-driven should be avoided to ensure energy efficient processing.

Verdict

Conditional productive-use potential

Challenges

- Low-income business that is capped by number of customers
- Non-essential good
- Difficult to identify target customers or areas

Conditions for Success

- Used in high traffic area and/or used as supplementary income stream for complementary business

FRUIT DRYING

Introduction

Drying is a preservation technique that uses convection to remove moisture from food. Food dryers (also called dehydrators) were popularized for their ability to be constructed locally and generate income for users. Here we investigate whether there are opportunities for solar electricity to improve this technology's productive-use case.

Overview of Technology

Food dryers use heat and air flow to remove moisture content from biomass, such as fruit, vegetables, spices, animal products, and grain. The drying process removes moisture and preserves the dried matter. Dryers can be broadly categorized into two categories: passive and active.

Passive dryers utilize glass or semi-transparent material to convert sunlight into heat, which increases the temperature of air in large collector trays. The hot air naturally rises and passes through drying chambers where it removes moisture before exiting the dryer. Passive dryers are typically very large in height and length.

Active dryers use electricity to replace the either one or both of the heating or convection processes. Fully electric dryers use heating elements to generate heat and fans to convect hot air through the drying chambers. Active dryers are able to dry food much with more consistency and greater speeds. They are also smaller than passive models and can be found in domestic kitchens.

Terminology: Solar Dryers

As passive dryers utilize solar energy, they are often called solar dryers. For this research, we specifically are interested in investigating the use of solar electricity in active dryers. To prevent confusion, we avoid the term "Solar Dryer" and use the term PV (Photovoltaic) Dryer to refer to an active dryer powered by solar electricity.

TECHNOLOGY OVERVIEW		
Model	Passive	Active – Household Size
Typical Power	-	500 – 1 kW
Temperature Range	Depends on weather, typically < 60° C	40 – 75° C
Drying Area	2 – 4 m^2 for Box Dryers	0.5 – 1.5 m^2
Advantages	No Operational Costs Large Drying Area	Quality Control Drying Speed
Disadvantages	Difficult to Dry in One Day Bulky Sensitive to Weather	Energy Intensive

Limitations of Modeling

The drying process has many variables that can influence the final product and energy consumption, such as initial moisture content, final moisture content, air flow speed, temperature, drying time, and more. Rather than model the relationship between all of these parameters, we based our inputs on the outcome of tests described in literature with known results.

Additionally, the selection of fruit or biomass for drying can affect the drying time and selling price. We selected mangoes as a representative use-case, as they are common in Tanzania and are one of the more commonly dried fruits. The results of our analysis may not be representative of edge-cases such as drying cash crops.

Productive-Use Case Analysis: Fruit Drying for Local Markets

For this technology, we model a fruit drying business using an electric dryer that sells products to local markets. The results are discussed with the following model, which looks at the same business marketing to high end customers.

JOBS TO BE DONE	
Operator	Generate income
Customer	Enjoy consumption of food

Original Business Scenario: Fruit Spoilage

The harvest seasons for fresh fruit comes in waves. Many rural farmers and households with fruit trees experience a glut of fresh fruit during certain periods of the year, resulting in the fruit being sold for low prices or going to waste.

New Business Scenario: Fruit Drying for Local Markets

An entrepreneur collects fresh fruit in the evening. In the early morning hours, the fruit is sliced and put into an electric dryer powered by solar electricity. After 8 hours of drying, the fruit is removed and packaged into small plastic packets. Once per month during major market days, the dried goods are taken for sale and distribution to small shops and vendors in the surrounding areas.

Technology Inputs and Assumptions

For the dryer, we modeled our business to be using an Excalibur 3926TCDB Electric Food Dehydrator, which operates at 600W and has a temperature range of 105 – 165° C. A duty cycle of 50% was assumed for the heater operating at 50C. A $400 CAPEX cost was based on quotes from online retailers. Although the product has a 10 year lifetime, a 3 year capitalization period was used for reasons described in the Methodology.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$400
Capitalization Period	Years	3
Power	W	600
Duty Cycle	%	50%
Capacity	m^2	1.4

Business Inputs and Assumptions

From literature research, 1 m^2 of drying area is estimated to hold 6kg of wet mango[6]. Assuming 10% final moisture content by weight and an 85% initial moisture content, the dried mangoes weigh 16.7% of the wet weight[7]. The drying time is estimated to be 11 hours based on literature[8].

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Loading Capacity	kg/m^2	6
Dry-to-Wet Ratio	%	16.7%
Drying Time	h	11
Market Price for Dry Mango	$/kg	$1.40
Mango Weight	kg/mango	0.2
Farm-gate Price	$/mango	$0.009
Seasonal Utilization Factor	%	83%

To determine a local market price, we re-packaged dried fruit into small bags commonly used to sell spices and marketed them to small-scale vendors, who were willing to buy a 125g bag for 400 TZS ($0.17) so that they could resell it with a 25% mark-up.

Material costs for mangoes were estimated to be 20 TZS ($0.009) each, 20% of their local market price during the peak season. Packaging costs were excluded from the model due to the high variation in pricing options.

Although mangoes are assumed to be in season only part of the year, we assume that other products with similar unit economics could be dried during the off-season. We assumed the dryer was operational 10 months out of the year due to weather, resulting in an 83% utilization factor.

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$0.18	$0.18	$0.18
Hourly Operating Expenses	$/h	$0.33	$0.21	$0.15
Hourly Gross Profit	$/h	($0.16)	($0.04)	$0.02
Daily Gross Profit	$/day	($1.71)	($0.39)	$0.27
CAPEX over Gross Margin	%	(26%)	(114%)	160%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	No
Gross Margin More Than $8/day	No
Predictable Demand	No
Capex over Gross Margin < 33%	No

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	No change
Labor	No change
Costs	Spending shifted from other sources or increased
Service Quality	New product available

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Productive-Use Case Analysis:
Fruit Drying for High End Markets

In this model, we look at the performance of a fruit drying business marketing products toward high end customers. All inputs are identical to the previous model, with the exception of the sales price.

JOBS TO BE DONE	
Operator	Generate income
Customer	Enjoy consumption of food

Original Business Scenario: Fruit Spoilage

The harvest seasons for fresh fruit comes in waves. Many rural farmers and households with fruit trees experience a glut of fresh fruit during certain periods of the year, resulting in the fruit being sold for low prices or going to waste.

New Business Scenario: Fruit Drying for High-end Markets

An entrepreneur collects fresh fruit in the evening. In the early morning hours, the fruit is sliced and put into an electric dryer powered by solar electricity. After 8 hours of drying, the fruit is removed and packaged into small plastic packets. Once per month during major market days, the dried goods are shipped to grocery stores that sell products to international and wealthy customers.

Technology Inputs and Assumptions

All technology inputs and assumptions are identical to those in the previous model.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$400
Capitalization Period	Years	3
Power	W	600
Duty Cycle	%	50%
Capacity	m^2	1.4

Business Inputs and Assumptions

Our selling price was based on a survey of dried fruit sold in supermarkets, which was typically sold at 6500 TZS ($2.82) per 80 grams. Assuming a 50% margin, the selling price is calculated at $17.66 per kilogram.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Loading Capacity	kg/m^2	6
Dry-to-Wet Ratio	%	16.7%
Drying Time	h	11
Market Price for Dry Mango	$/kg	$17.66
Mango Weight	kg/mango	0.2
Farm-gate Price	$/mango	$0.009
Seasonal Utilization Factor	%	83%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$2.25	$2.25	$2.25
Hourly Operating Expenses	$/h	$0.33	$0.21	$0.15
Hourly Gross Profit	$/h	$1.91	$2.03	$2.09
Daily Gross Profit	$/day	$21.06	$22.38	$23.04
CAPEX over Gross Margin	%	2%	2%	2%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	Yes
Predictable Demand	No
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	No change
Labor	No change
Costs	Spending shifted from other sources or increased
Service Quality	New product available

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	No
Desirable at Half Capacity	Yes

Discussion of Results

There is a significant difference between the productive-use potential for a fruit drying business that sells its product to local and one that sells its product to high end customers.

When selling to local customers, the product does not generate enough income to cover operating costs at the base tariff, and is barely profitable under ideal conditions. This is due to the extremely low value place on the product by most local consumers: a single mango was valued at $0.047 (107 TZS) when dried. While this is an increase over the farm-gate price, it is comparable to fresh mango, which is often sold at $0.043 (100 TZS) or above during the peak season.

This implies that consumers do not see value in the drying process. One interview participant expressed this bluntly when they asked why anyone would want to eat dried fruit instead of fresh fruit. In evaluating this productive-use case, it is clearly not desirable for the operator and the customer alike.

When targeting higher end customer segments, the business becomes desirable for operators who can make sizable margins on their products. The product appears to be desirable for this customer segment as well, which is evidenced by the inclusion of dried fruit products in upscale and larger grocery stores in Tanzania.

Accessing these high value market is not an easy challenge for equipment operators, who must develop sophisticated branding and sales channels. This creates difficulty scaling this product for productive-use in off-grid contexts: to make the business work, customers need to be empowered, savvy business owners.

The choice of technology is secondary in importance to the market access. Although passive driers have lower costs overall, the cost of electricity in our model are between 2 – 3 dollars per day. While this can be significant over time, it makes up only 10% of daily earning potential and might improve quality control.

Conclusions

From our analysis we conclude that PV dryers are potentially viable as productive-use assets but their profitability depends upon the operator's ability to secure access to a high value market for the end-products. Without the right market, the productive-use case fails.

Although a PV dryer can use several kilowatt-hours of electricity per day, the costs are minor in comparison with the potential value of the end-product when sold in the right market. The know-how to secure those markets and manage the end-product quality is more valuable than the technology, and is also a bigger barrier to scale.

PV and other active dryers may be advantageous in areas with lower temperatures where passive dryers are impractical as they can provide consistent product quality through a controlled drying process.

Verdict

Conditional productive-use potential

Challenges

- Profitability depends on ability to sell into high value market
- Customers need training on sales and marketing
- Only minimal advantages over passive driers, may not be preferred

Conditions for Success

- Operator can create or access valuable sales channel

FLOUR MILLING

Introduction

Of all the technologies considered for this research, flour milling was the agri-business that off-grid industry stakeholders had the most interest in learning about. Likely that's because the process is so broadly relevant in rural areas: anywhere that cereal grains are grown, flour milling is applicable.

Not only do solar powered mills present a market opportunity, they also present an opportunity to reduce household labor and drudgery in areas where people still rely on manual milling methods such as mortar and pestle.

Flour milling is the process of breaking down food solids into fine particulate matter. For this research, we primarily focused on maize flour milling, the most common flour used in Tanzania.

TECHNOLOGY OVERVIEW			
Model	Hammer Mill (Small)	Hammer Mill (Large)	Small-scale Emory Mill
Typical Power	1 – 3 kW	15 – 30 kW	1 – 3 kW
Throughput	10 – 100 kg/hr	100 – 500 kg/hr	10 – 50 kg/hr
Advantages	Low maintenance Easy to fabricate	High throughput Easy to fabricate	Nutrient retention
Disadvantages	Low throughput	Energy Intensive	High maintenance costs Low throughput

Overview of Technology

In Tanzania, 95% of flour made by milling machines is ground in hammer mills, often called posho mills. These mills have spinning hammers that break grain into fine powder until it can pass through a screen and removed from the machine with the assistance of a blower. The mills are favored by operators for their simplicity: the majority of components can be easily made at local workshops.

Larger-scale hammer mills offer convenient service for customers, who often bring a bucket of grain to the mill and have it ground on the spot. This model suits rural contexts well, where people might travel to visit a miller only once per week on a market day. In off-grid areas, these hammer mills are powered by diesel or petrol engines.

Small-scale hammer mills have been designed as part of attempts to create a solar-powered alternative to diesel-mills in rural off-grid areas. The basic technology is the same as with larger-scale models, although the throughput generally drops as the input power is reduced.

Emory stone mills are less common in Tanzania and surrounding regions, but solar-powered units have been brought in for demonstration.

Many other mill technologies exist, such as pin mills, roller mills, and pounding mills, but these are less commonly found in Tanzania at the small scale.

Understanding Efficiency

We can reframe our understanding of mills by looking at efficiency rather than just power or throughput in isolation. To calculate efficiency (e), we divide throughput (T) by power (P):

$$e = \frac{T}{P}$$

In layman terms, efficiency is how much you get out for how much you put in. In this case, efficiency tells us how much flour we get for each unit of energy we use.

This is helpful because it forms a basis of comparison for mills of different sizes, or even for the same mill with different motors attached or under different configurations. A mill with higher efficiency will result in better unit economics than a mill with lower efficiency.

As an example, we can find the efficiency at which we achieve break-even unit economics under the assumptions used in our model (a $0.043 per kilogram service charge (r) and a $0.60 per kilowatt-hour tariff (t)). At break-even, our costs per kilowatt-hour equal our revenues per kilowatt-hour as shown below:

$$\frac{Revenue}{kWh} = er = t = \frac{Cost}{kWh}$$

$$\mathrm{e} = \frac{t}{r}$$

Solving the above, we find break-even efficiency to be 14 kg/kWh. We can now quickly evaluate the productive-use potential of different mills for our scenario: any mill with an efficiency lower than 14 kg/kWh will lose money under our given conditions.

Productive-Use Case Analysis: Flour Milling

In the following section, we model two small scale hammer mill businesses operating in rural areas. The first model is for a solar-powered mill operated in a populous area. The second considers the same mill located in a remote, sparsely populated area. Each model includes a hulling technology as well.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Mill maize into flour using minimal time, labor, and cost

Original Business Scenario: High Traffic Diesel Mill

On the weekly market day, farmers put their maize kernels into a bucket and carry it to the diesel powered mill at the local marketplace. At the mill, the farmers pay for the grain to be de-germinated and milled into flour, which is then carried back to the home and used in cooking. Women are primarily responsible for the transport labor associated with milling and carry up to 20kg at a time.

New Business Scenario: High Traffic Solar Mill

A new solar-powered mill is set-up in a remote area to replace a broken diesel mill. Farmers bring their maize to the mill in buckets and pay for it to be hulled and milled into flour.

Technology Inputs and Assumptions

For our mill, we modeled a small hammer mill based on a product undergoing ongoing testing in Tanzania that is reported to have 90 kg/h throughput using a 2.2 kW motor. We modeled the CAPEX costs at $500 based on a rough estimate of component costs. A 3-year capitalization period was used for reasons given in the methodology.

TECHNOLOGY ASSUMPTIONS: MILL		
Specification	Unit	Value
Combined CAPEX Costs	$	$1000
Capitalization Period	Years	3
Combined Power	kW	4.4
Net Throughput	kg/h	90

We also added a maize peeling and hulling machine into our model, which is a complementary service that farmers receive at diesel and on-grid mills. We based our machine specifications on specifications collected from an online survey of suppliers, who listed throughput in the ranges of 80 – 120kg per hour for a 2.2 – 3kW motor. We assumed operation at the lower end of the reported specifications and assumed a 2.2kW and 90kg per hour, and again assumed a $500 CAPEX price. Combined with the mill, the total throughput is 90 kg/hr using 4.4kW of power.

Business Inputs and Assumptions

We modeled our business based on data collected from interviews at mills in Tanzania, which typically charge between 70 TZS ($0.030) and 150 TZS ($0.065) per kilogram of maize milled. We modeled a 100 TZS ($0.043) per kilogram service charge, which we found to be typical. Off-grid millers using diesel-powered mills reported processing 450 kilograms on an average day, resulting in an equivalent 5 hour operating time for our solar mill.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Price per Kilogram	$/kg	$0.043
Screen Replacement	$/screen	$8.70
Screen Lifespan	h/screen	75
Daily Usage	h/day	5
Seasonal Utilization Factor	%	75%

Screen replacements were consistently estimated to cost around 20,000 TZS ($8.70), but the reported replacement frequency varied considerably between two weeks and nine months. We modeled screens to have a 75-hour lifespan to be conservative.

Flour milling is influenced by seasonality but this effect varies regionally based on the number of harvests and annually based on the success of the harvests. We estimated it to be a net 75%, based on 100% utilization for half the year and 50% utilization during the other half.

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$3.87	$3.87	$3.87
Hourly Operating Expenses	$/h	$4.52	$2.76	$1.88
Hourly Gross Profit	$/h	($0.65)	$1.11	$1.99
Daily Gross Profit	$/day	($3.23)	$5.57	$9.97
CAPEX over Gross Margin	%	(38%)	22%	12%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	Increase in time spent milling
Labor	No change
Costs	No change
Service Quality	No change

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

There is a large variation between the outcomes of the business due to the tariff as a result of the high power. The solar mill is close to meeting our criteria for desirability on the base tariff but meets all criteria on the ideal tariff. On the conservative tariff, the mill is not profitable.

For the farmer using the mill, the service is similar to what they would expect from a diesel mill but slightly slower. In a situation with a solar mill competing directly with a diesel mill, we find it likely there would still be demand: on crowded market days, most of the time spent milling is actually just waiting in line.

For distributors, the product might be difficult to scale as the ideal market for this product is also the ideal market for a diesel mill. If there is another mill or mills, the competition would weaken the business case. A scenario where a less populated area is targeted instead is considered in the following model.

Productive-Use Case Analysis: Flour Milling

Here we present a model of a solar-powered mill that is operated in a less densely populated area. All technology inputs are the same as in the previous model, but some business inputs were changed.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Mill maize into flour using minimal time, labor, and cost

Original Business Scenario: Remote Diesel Mill

On the weekly market day, farmers put their maize kernels into a bucket and carry it to the diesel powered mill at the local marketplace. At the mill, the farmers pay for the grain to be de-germinated and milled into flour, which is then carried back to the home and used in cooking. Women are primarily responsible for the transport labor associated with milling and carry between 10 – 20kg at a time.

New Business Scenario: Nearby Solar Mill

A new solar-powered mill is established in a remote village. Rather than bring their maize to the diesel mill at the market, farmers use the solar mill to save time.

Technology Inputs and Assumptions

All technology inputs and assumptions are identical to those in the previous model.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$1000
Capitalization Period	Years	3
Power	kW	4.4
Throughput	kg/h	90

Business Inputs and Assumptions

Given the proximity, we increased the service charge of the mill to $0.065 (150 TZS) per kilogram, which is the higher end of service charges reported by millers.

Since the mill is located remotely, a smaller population uses the mill than in our previous model. We assumed 100 households used the mill and each consumed 370kg of maize flour per year – this is the same household consumption rate used in our rice hulling model and is consistent with reports of an average 73kg of maize consumption per person per year and average 5 person households. This would result in an average usage of 1.2 hours per day with a 100% utilization rate.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Price per Kilogram	$/kg	$0.043
Screen Replacement	$/screen	$8.70
Screen Lifespan	h/screen	75
Daily Usage	h	1.2
Seasonal Utilization Factor	%	100%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$5.87	$5.87	$5.87
Hourly Operating Expenses	$/h	$4.52	$2.76	$1.88
Hourly Gross Profit	$/h	$1.35	$3.11	$3.99
Daily Gross Profit	$/day	$1.62	$3.74	$4.79
CAPEX over Gross Margin	%	56%	24%	19%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	No
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	Decreased travel time, Increased milling time
Labor	Decreased travel labor
Costs	Increase in milling costs
Service Quality	No change

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

This model shows that an off-grid mill operator operating in a sparsely populated area could have a profitable business, although the income earning potential is not quite enough to meet our criteria of being a desirable business. In comparison with the previous model, the increased service charge improved the unit economics but not by enough to make up for the decreased utilization of the machine in our base scenario.

From the customer perspective, the mill offers convenient services that could plausibly be enough to make up for the increased service charge. In interviews with mill customers, many reported walking up to 10km with their bucket of maize in order to reach the closest mill, ultimately costing them their entire day.

Targeting less densely populated areas opens up the market for solar mills, but it is easy to imagine scenarios where an operator earns a fraction of what is expected, such as a situation where farmers mill their grain at a diesel mill because they were going to the market anyway. Distributors that want to ensure their mills succeed will need to spend more time assessing each customer and potential market.

Limitations of Modeling

Our model excludes degerminating services as part of the business. Given the widespread preference for these complementary services, it is possible that demand for the milling services would decline if the services were absent and that our mill's hourly operation would not be achievable. Alternatively, adding a de-germinating machine would increase costs.

All About Degermination

Most grain is not milled directly into flour. Instead, the grain is first broken down into pieces in a process called degerminating (also called debranning, hulling, or peeling). In this process, the endosperm is separated from the germ and/or bran.

In Tanzania, the degerminating process for maize occurs in a single machine. When done dry, the process is called *Kuparaza* and removes part of the germ, allowing the maize endosperm and bran to be milled into whole grain flour. When processed with water, the entire germ and bran are removed, allowing the remaining maize endosperm to be milled into refined flour.

Most people in Tanzania have their grain degerminated prior to milling when it is an option. Often times, the operator provides free degerminating services in exchange for keeping the bran, which they can resell for feed.

When the grain is not degerminated, customers receive whole maize meal, which is often sifted to produce a semi-refined flour.

Conclusions

Our analysis suggests that flour milling can be productive on solar electricity but that the business case is sensitive to a number of inputs. There is productive-use potential, but effort is required to identify markets where the product will prove successful.

Our models suggest that a solar mill faces distinct challenges depending on the environment in which they are operated. In a high traffic area, the mill has decent earning potential but may also face competition that can weaken or erode the profitability. In remote areas with fewer people, the mill's business case depends on charging higher prices for the services and capturing all of the local demand for milling.

The efficiency of the mill technology has a major effect on the productive-use case. We found large differences in the reported performance between mills of similar architecture (e.g. between small-scale hammer mills), but the underlying cause of the differences is unclear. Given that small-scale mills have relatively high power consumption, any change to efficiency or tariff can have a significant impact on the resulting business case.

More work needs to be done to understand how important de-germinating technologies are to the success of small-scale flour milling businesses. The inclusion of a hulling machine improves the services provided to the end-user, but at the expense of adding costs to our operator's business.

More research needs to be done on the willingness to pay for milling services at different prices. As shown, small increases in service charges can greatly improve the earning potential and understanding this lever can help identify new market opportunities.

Relative to the other technologies presented in this paper, small-scale grain mills are undergoing the most research and development and we expect that new insights will come from that work and add depth to this research over the next several years.

Verdict

Conditional productive-use potential

Challenges

- Needs large population as each household has fixed earning potential
- High power consumption makes business sensitive to tariff
- Can be difficult to identify target areas due to competition

Conditions for Success

- Areas with numerous maize growing households and low presence of other types of mills

PEANUT SHELLING

Introduction

Rich in fats and oils, groundnuts can be a nutritious and lucrative crop for smallholder farmers. However, it is extremely laborious to process by hand: users report shelling peanuts at a rate of 0.5 – 1.0 kg/hr when done by hand. Mechanized shellers present an opportunity to do this same process hundreds of times faster.

Overview of Technology

Peanut shellers, also called groundnut shellers or peanut/groundnut decorticators, separate the edible part of the peanut from its outer shell. Many peanut shellers have a studded, rotating drum that crushes the shelled nuts against a screen. The unshelled nuts and broken shells pass through holes in the screen, where they are either collected or else further separated and cleaned with shake table and winnowing mechanisms.

Manual-powered peanut shellers can be found in peanut-growing regions in Tanzania. These shellers are often low-cost and result in breakage of peanuts, reducing their selling price. Manual shellers in southern Tanzania were constructed of wood and users reported worse performance than manual shellers described online.

Mechanized shellers quicken the shelling process, which can also result in higher end-quality of the nuts by reducing breakage and separating the shelled nuts from dust and bits of shell. These shellers can operate at a range of input power levels, with higher power generally resulting in higher throughput.

TECHNOLOGY OVERVIEW			
Model	Hand-Powered	Small Mechanized Sheller	Medium Mechanized Sheller
Typical Power	-	375 – 500 W	2 – 3 kW
Throughput	5 – 50 kg/hr	100 – 150 kg/hr	200 – 800 kg/hr
Advantages	Low-cost Locally Made	Low power	High throughput Can include separation and cleaning stages
Disadvantages	Low throughput No cleaning or separation Inconsistent performance	Minimal cleaning Often has high rates of unshelled or broken product	High Power

Productive-Use Case Analysis: Peanut Shelling

For our analysis, we model a business operating a small mechanized peanut shelling machine that is powered by solar and offers shelling services to nearby farmers.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Shell peanuts harvest using minimal time, labor, and cost

Original Business Scenario: Hand Shelling

After harvest, farmers collect their peanuts into bags and store them at their farm or house. Over a period that can last for months, family members will spend their evenings shelling the peanuts by hand and separating the shells from the edible nuts. Sometimes they hire additional help in order to complete the labor faster. Most small farms produce 360kg of shelled peanuts per acre[9].

New Business Scenario: Solar Shelling Machine

A small peanut shelling business is opened in a remote area where peanuts are grown. The business offers shelling services and charges by the kilogram.

Technology Inputs and Assumptions

For the technology, we modeled a small-scale sheller based off of a sheller described and tested in Hoque, 2018, which had a shelling throughput of 110 – 128 kg/h in field trials[10]. The CAPEX costs were modeled at $600 (double the cost estimate given in the paper) and the capitalization period was assumed to be 3 years.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$600
Capitalization Period	Years	3
Power	W	375
Throughput	kg/h	110

Business Inputs and Assumptions

To model our business, we collected data from users in southern Tanzania who reported paying $1.30 (3000 TZS) to have a 20kg bucket of peanuts shelled. The rate was consistent whether paid for manual or for mechanized processing.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Shelling Price	$/bucket	$1.30
Bucket Size	kg/bucket	20
Daily Usage	h	7.2
Seasonal Utilization Factor	%	25%

For the utilization rate, we assume the peanuts are processed for a span of 3 months after harvest, equivalent to a 25% utilization rate. We assumed a 7.2 hour daily utilization rate, which is sufficient to serve 100 farmers that grow peanuts on 2 acres each.

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$7.15	$7.15	$7.15
Hourly Operating Expenses	$/h	$0.38	$0.23	$0.15
Hourly Gross Profit	$/h	$6.78	$6.93	$7.00
Daily Gross Profit	$/day	$48.78	$49.86	$50.40
CAPEX over Gross Margin	%	4%	4%	4%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	Yes
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	Decreased shelling time
Labor	Decreased shelling labor
Costs	Increased shelling costs
Service Quality	No change

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	Yes

Discussion of Modeling Results

Our model shows that peanut shelling businesses can be highly productive when operated on solar due to the valuable services they provide and the high efficiency of the technologies.

The business meets all of our criteria to be considered desirable by the equipment operator at any of the modeled tariffs. Energy costs relative to the revenue are extremely low, the services have a dependable market, and the CAPEX costs can be quickly recovered.

From the customer perspective, a mechanized shelling machine has clear time and labor saving benefits over performing the labor manually or even with a manual shelling machine. In comparison with paying laborers, we find it likely that people would prefer the mechanized service as it is more reliable and requires less supervision.

Transportation and portability could potentially impact the business model, but we believe the high margins enable this product to overcome transportation challenges.

For distributors, this product is straightforward to scale. The technology and business model are simple and the productive-use case can be successful even in remote areas or areas with competing businesses.

Conclusions

Our analysis of peanut shelling machines suggests that they have great productive-use potential and well-suited for being solar-powered: they have low power consumption, provide valuable services, and are profitable even when operated for brief periods of the year.

Unlike other crops, we do not find that a peanut shelling machine would be adversely affected by transport or portability requirements. In addition to the low costs of transport relative to the cost of service, we find that shellers can be profitable serving small populations, which minimizes transportation expenses.

We also did not find reason to believe that other mechanized shellers would out-compete a solar-powered model. A solar-powered sheller offers more convenience than on-grid shellers and better service than manual shellers. We did not find any engine-driven shellers operated in a portable service model during our research.

If planning the implementation of a solar-powered peanut sheller, the specific technology design should be made in consideration with the local market size for the sheller services, average farm size and production, growing seasons, and whether households sell or consume the peanuts.

Verdict

High productive-use potential

Challenges

- Supply chain for small-scale models not well developed

Conditions for Success

- Any off-grid area growing peanuts

COFFEE PULPING

Introduction

Coffee is one of East Africa's most lucrative cash crop for farmers and requires many steps of production before it can be cupped. Coffee pulping is one of the more laborious steps of the production process, when the coffee bean is removed from the cherry so that it can be dried and further processed for brewing.

Overview of Technology

Most farms in northern Tanzania use manual pulping machines similar to the one shown in the picture above. In manual machines, coffee cherries and water are poured into an inlet at the top. A hand crank feeds the cherries into the machine where a rotating drum splits the cherries and expels the beans at the front of the machine.

Most of these manual coffee pulping machines in northern Tanzania are decades old. Not every coffee grower owns a pulping machine, and neighboring farms often share access. Laborers also bring machines directly to farms to provide pulping services.

Because of their design, the coffee pulping machines can be retrofitted to be powered by an alternate source. One local innovator built stands that allowed the pulping machines to be bicycle-driven, which increased the throughput dramatically. Small motor driven units are also possible.

In Northern Tanzania, larger coffee pulping machines are sometimes owned and operated by cooperatives. Like the manual pulping machines, most of these machines are decades old but still in regular use.

TECHNOLOGY OVERVIEW				
Model	Manual Pulping Machine	Bicycle Driven Machine	Small Motor Driven Machine	Large Motor Driven Machine
Power	Hand	Bicycle	.375 - 2.25 kW	4+ kW
Throughput	90 kg/hr	450 kg/hr	200 - 5000 kg/hr	3000+ kg/hr

Productive-Use Case Analysis: Coffee Pulping

For our business case analysis, we model a small motor-driven coffee pulping machine powered by solar that is operated as a service for neighboring farms.

JOBS TO BE DONE	
Operator	Generate income
Farmer	Pulp coffee cherries using minimal time, labor, and cost

Original Business Scenario: Manual Pulping

And picking coffee cherries from trees on their farm, farmers put their harvests in bags and pile them in an area on their farm that they designate for pulping. Many farmers choose to hire laborers to do the pulping, and arrange for a manual pulping machine to be brought from a neighboring house that the laborer can use to accomplish the task. As a single acre can produce over 1 ton of coffee cherries, pulping typically takes multiple days even for small farms.

New Business Scenario: Solar Coffee Pulping Machine

A new coffee pulping business is opened in a coffee growing area. Farmers that wish to use the service can bring their coffee to the machine and have it processed there for a fee. After the processing is complete, they transport their peeled coffee back to their farm for drying.

Technology Inputs and Assumptions

For the technology, we model our technology based on a CAPE Estrella No. 5 coffee pulping machine, which is powered by a 1HP motor and achieves 1200 kg/h throughput[11]. Two channel pulping machines are commonly used in northern Tanzania, although they are usually smaller and lighter than the modeled machine. We modeled a CAPEX cost of $500 based on a survey of online suppliers and local retailers.

TECHNOLOGY ASSUMPTIONS		
Specification	Unit	Value
CAPEX Costs	$	$500
Capitalization Period	Years	3
Power	W	750
Throughput	kg/h	1200

Business Inputs and Assumptions

To calculate the business case, we surveyed coffee-growing households. Farmers reported paying 100 TZS ($0.043 USD) per 15kg bucket of cherries to be peeled. We estimated a utilization factor of 40%, as farmers reported the harvest season and pulping process spanned five months. For a daily usage, we modeled a 1.1 hour operating period, which is enough to serve 100 farms growing 1200kg of coffee cherries.

BUSINESS INPUTS AND ASSUMPTIONS		
Specification	Unit	Value
Shelling Price	$/bucket	15
Bucket Size	kg/bucket	$0.043
Daily Usage	h	1.1
Seasonal Utilization Factor	%	50%

Calculations

HOURLY UNIT ECONOMICS				
Calculations	Unit	Conservative Tariff	Base Tariff	Ideal Tariff
Hourly Revenue	$/h	$3.44	$3.44	$3.44
Hourly Operating Expenses	$/h	$0.75	$0.45	$0.30
Hourly Gross Profit	$/h	$2.69	$2.99	$3.14
Daily Gross Profit	$/day	$2.96	$3.29	$3.45
CAPEX over Gross Margin	%	31%	28%	26%

Evaluation of Desirability and Viability

DESIRABILITY OF BASE CASE FOR OPERATORS	
Profitable Business	Yes
Gross Margin More Than $8/day	Yes
Predictable Demand	Yes
Capex over Gross Margin < 33%	Yes

DESIRABILITY OF BASE CASE FOR CUSTOMERS	
Time	Decreased shelling supervision time, Increased transport time
Labor	Increased transport labor
Costs	Increased transport costs
Service Quality	No change

VIABILITY OF PRODUCT TO SCALE	
1 Day Product Training	Yes
No Special Functions Necessary	Yes
Desirable at Half Capacity	No

Discussion of Modeling Results

The unit economics of a small-scale solar-powered coffee pulping machine are desirable for an operator, who can pulp as much coffee in an hour as an individual could in a day.

For the farmer, the service is faster but they face challenges related to transport of their goods that might make the service undesirable. For a farmer that pays for coffee shelling services, the primary benefit to using a powered machine is that it reduces any need to supervise or organize someone to do the labor. But this switch would come at the cost of organizing transport for large amounts of bulky goods, paying for that transport, and spending personal time traveling to the machine and back. We find it unlikely that most farmers would make this switch.

One factor that complicates the transport is terrain. Coffee grows at high altitudes and the mountainous environment can increase the difficulty of travel, especially on dirt roads.

Another factor that might make transport unappealing is that despite coffee's high market value, the pulping process is not valued particularly high relative to the mass: based on our data, the local market rate to pulp coffee is just $2.87 per 1000 kg. If cost is a proxy for difficulty, then coffee pulping is not very difficult for farmers and there is little incentive to change the way things are done.

This productive-use case would be difficult to scale due to challenges associated with identifying appropriate sites. While potentially profitable, the success of the business depends very much on the local conditions such as population density and transportation infrastructure.

ABOVE: An engine-driven pulping machine at an off-grid coffee cooperative.

Mini-Case Study:

Coffee Cooperatives and Alternative Business Models

Many small-scale coffee farmers are organized into cooperatives through which they sell their coffee. Some of the larger cooperatives offer processing services: farmers deliver their coffee cherries and the cooperative will pulp, dry, sort, and grade it before bringing it to market.

Because all processing is centralized at the cooperative site, the issue of portability is lessened: customers receive more value for the cost of transport. This makes our model more viable.

However, coffee cooperatives also have higher quality standards and often must be pulped immediately after harvest. In the Kilimanjaro region, coffee is harvested during the day, resulting in large batches being processed at night. Under these conditions, we would expect the operating cost of solar to be much higher, and might not be competitive with engine-driven models.

Conclusions

Despite favorable unit economics and relatively simple technical challenges, the transportation and portability requirements of our business model hinder the ability for solar-powered coffee pulpers to be operated productively.

This is an example of a product where the technology is productive-use on paper, but is difficult to use in an actual business. If there were a cheap portable power source available or a solar grid connecting numerous coffee farms, a different conclusion might be reached.

Those interested in boosting incomes of coffee-growing communities might have better luck with non-technical interventions, such as securing better markets.

Verdict

Low productive-use potential

Challenges

- Huge volume of coffee necessary to reach capacity
- Transport of coffee cherries is difficult and potentially costs more than services provided
- Hiring laborers is convenient and low-cost service

#5 CONCLUSIONS

CONCLUSIONS

Summary of Findings from Evaluations

Ten different agriculture-related business cases were considered and evaluated for their potential to be successfully operated and scaled when using solar power. A business model was developed for each technology use-case to understand its profitability and barriers to adoption and scale. These findings are presented in detail in the individual sections.

A recommendation was given for each productive-use case on whether the products evaluated should be further developed and brought to market by the off-grid energy sector. Of the ten technologies evaluated:

- 2 were considered to have low productive-use potential and be difficult to successfully scale
- 6 were considered to have conditional productive-use potential, such that there are opportunities for them to be implemented successfully if certain criteria are met
- 2 were considered to have high productive-use potential and have relatively low barriers to scale

One of the most important conclusions from our paper is that productive-use businesses need to be viewed outside of just a technology-focused lens.

While we generally view costs of energy, product efficiency, and CAPEX cost as barriers to the scaling of productive-use appliances, our analyses showed that other variables were just as (if not more) important in determining an appliance's productive-use potential.

By understanding the trends of how different variables affect the outcome of a business, we help build a foundation of insights that could potentially be used as a high level evaluation tool for new productive-use opportunities. What this means is you do not need to be a subject matter expert (or conduct enough research to write an 80-page research paper) to make insightful analyses.

In further sections we present a selection of brief insights regarding variables that appeared frequently in our analysis and how their values tended to inform our conclusions.

Reflection on Modeling Approach

The business modeling methodology was applied to ten different technologies. From this experience, we reached an understanding of the utility and limitations of the modeling approach.

The virtues of this approach were made clear during the review process of this paper. Because the models required assumptions to be made explicit, it was easy to for readers to point out where they were either getting lost or felt that assumptions were unbelievable. These points of feedback also helped uncover other benefits of the methodology, which is that it is trivial to change assumptions or to add additional details.

While it is easy to change a model and its values, these degrees of freedom make it challenging to present this kind of model on paper. If we modeled an existing business, we would have a clear source of data to feed into our model. But in our case, we are modeling a new business and there is ample room for debate on what assumptions are valid and what level of detail is needed. These debates are best had through dialogue; in written format, an appropriate balance of brevity and thoroughness is difficult to achieve and remains subject to the audience reading it.

These insights help us conclude that a model built with this methodology is best used as an active centerpiece of conversation. To make full use of the approach, it’s important to keep things dynamic and responsive to the situation.

Key Insights from Evaluations: Important Variables

Earnings per Acre: Supply as a Limiting Factor

The earning potential for an agricultural processing business is always limited in some form by the surrounding population and cultivation. For businesses where the service is used for the entire harvest, the income earning potential will be limited by the acreage.

Businesses that earn more per acre are less dependent on scale and thus more likely to be successful in remote areas or in areas with competing products. These kinds of business are well-suited to areas with high agricultural productivity, regardless of whether there is a dense population present.

We estimated the earning potential of services provided on a per-acre business and found that it closely tracked with our assessments.

Earning Potential per Acre		
Productive-Use Case	Unit	Gross Profit per Acre
Coffee Pulping	$/acre	$2.99
Maize Shelling	$/acre	$4.35
Peanut Shelling	$/acre	$23.40
Oil Pressing	$/acre	$25.88

Earnings per Household: Demand as a Limiting Factor

Does a farmer growing maize on 100 acres consume 20 times more maize flour per year than a farmer growing maize on 5 acres? No!

Some businesses are not improved by serving farms of bigger size and having more material to process. While services like maize shelling depend on the local acreage and scale by land area, services like maize milling depend on the local consumption and scale by population.

This insight is particularly relevant for productive-use businesses that provide food-related services. The table below shows how this is relevant for rice hulling and maize milling and how markets need to be sized according to the local population rather than area.

We can also apply this to fruit juicing, sugarcane juicing, spice grinding, and fruit drying in a similar manner: having access to additional raw material inputs to process does not improve the business.

Demand-limited businesses are best suited to densely populated areas rather than areas with high levels of cultivation: in cases like these, it is better to serve 100 small farms than 1 large one.

Gross Profit Calculated per Acre vs. per Household		
Productive-Use Case	Potential Annual Gross Profit per Acre	Limit of Annual Gross Profit per Household
Rice Hulling	$18.00	$5.10
Maize Milling	$21.42	$4.76

Market Location: What is the final destination for the product?

The ultimate sales location for the end-product of any processed goods plays an important role in whether a processing technology should be solar-powered. If the customers for products of the processing are located on-grid, it is less advantageous to shift the processing off-grid where costs are higher.

A clear example of this is with rice milling. For rice that is consumed in the household (i.e. the market for hulled rice is off-grid), it is an advantage to have a nearby rice huller that can be used regularly to mill small amounts of rice.

However, for rice that is sold to traders and brought to urban markets (i.e. the market for hulled rice is on-grid), the rice is better off being processed at an on-grid rice mill, which is faster and offers additional value-add services.

Transport Load: Volumes and Density

Since solar systems are usually not portable, transportation is an important consideration for any productive-use business.

Services that are used for small volumes of material face fewer transport issues than services that are used to process large amounts of material. For example, a solar powered maize shelling business would require a farmer's entire harvest (2-3 tons per acre including cobs) to be transported at once, which is a logistical challenge. Maize milling, however, requires an average of 7 kilograms of maize to be transported per household per week, which presents its own set of challenges but is plausible without access to cargo vehicles.

Ultimately, transport is an issue that can be overcome with time or money. But is it worth the trouble?

The table below shows how much revenue is earned per ton of material transported. Another way to think about this is if a customer goes through the trouble of moving a ton of material to an agro-processing business and back, what is the value of the services they expect to receive?

In some instances, the value of the services justifies the transport. In others, not so much.

Earning Potential per 1000 Kilograms Transported		
Productive-Use Case	Unit	Revenue per Ton Transported
Maize Shelling	$/ton	$2.44
Coffee Pulping	$/ton	$2.87
Oil Pressing	$/ton	$65.00
Peanut Shelling	$/ton	$195.00

Essential Processes vs. Consumer Goods

Some of the productive-use businesses provided services that were more essential than others: milling flour and rice is an important service for small-scale farmers, whereas drinking juice and eating dried fruit is relatively more of a luxury.

It is difficult to generalize the demand for consumer goods marketed in off-grid areas, which is why productive-use cases such as juice-making were considered conditionally productive.

Next Steps

This research acts as a starting point for multiple follow-on projects that aim to spur the successful development and adoption of productive-use technologies.

Development of Agro-processing Machines

One project that we have already begun work on is the further development of agro-processing technologies that we found to have high productive-use potential, namely peanut shellers and oil presses. We have also begun work on a maize mill that is unproven at the small-scale but that we believe has potential to make the productive-use case for flour milling more attractive. This project will involve focusing in and adding depth to the understanding of these productive-use cases, developing prototypes, and piloting them to hopefully prove some of the conclusions made in this paper.

Further Refinement of Insights into a Toolkit

We would like to further develop the insights made in this conclusion section into a tool that can be used to create high level evaluations of productive-use cases. By asking the right questions, we may be able to provide a short-cut to conclusions and quickly assess productive-use opportunities.

New Product Evaluations

Building off of the toolkit described above, we would like to conduct a broader landscape assessment and understand what other opportunities can be taken up by the sector.

Revision and Addition of New Models

Finally, we hope this research spurs dialogue around productive-use technologies and that people begin to challenge our models with their own data and evidence, especially in instances where they have witnessed successful productive-use applications. Those experiences add depth to the understanding of what factors drive success and those lessons help the off-grid energy sector make focused, strategic efforts to improve livelihoods.

#6 ANNEXES

A1: REFERENCES

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A2: MODELING STAND-ALONE SYSTEMS

Overview: The Costs Of Energy in Stand-Alone Systems

The cost of energy is an important variable in evaluation of productive-use businesses. For grid-tied users, the cost of energy is typically a fixed rate set by the utility provider. With stand-alone solar systems, the cost of energy is often a more complex calculation that is influenced by a number of other variables.

Stand-alone solar system providers might find the cost of energy unintuitive, since users that purchase solar systems do not actually pay per unit of energy consumed. But this calculation is analogous to how businesses depreciate CAPEX and spread out equipment costs over their lifespan.

In this case, we take it a step further: instead of depreciating our CAPEX over a fixed time period, we depreciate it based on how much we use it. This allows us to understand the unit economics of our productive-use businesses.

At its most basic, we can think of the cost of energy as follows:

$$Cost\ of\ Energy = \frac{Total\ System\ Cost}{Total\ Energy\ Used}$$

From this starting point, we can calculate the cost of energy for any stand-alone system.

Below we present a few methods that practitioners can use to calculate the cost of energy for their stand-alone systems so that they can easily work with the models that we use in this report. Following the theory, we present a few practical examples that demonstrate how to apply this in practice.

If you get overwhelmed in the theory, we recommend skipping straight to the practical examples.

This guide is primarily directed at laypeople looking to make rough calculations, rather than experienced technical service providers seeking precise answers.

Guide to Calculating The Cost of Energy

Step 0: Before You Start

To complete this exercise, you will need the following:

- Information about a solar system that you want to calculate the cost of energy for, including lifespan and price data
- Assumptions about the productive-use business that you want to power, particularly the usage pattern and the appliance power consumption

Before we get started, we will rewrite equation 1 by normalizing it over a yearlong period. We do this so that we can easily work with components that have different lifespans, such as panels and batteries, without worrying about residual costs.

$$Cost\ of\ Energy = \frac{Total\ System\ Cost\ per\ year}{Total\ Energy\ Used\ per\ year}$$

Note that we are basing this on the energy used rather than the energy produced. This is an important distinction. If your system only gets used a short period per year, our productive-use business must still recover the entire system costs within that time period as well.

Step 1: Calculating Total System Costs per Year

Our next step is to calculate the annual system depreciation. The total depreciation is a sum of the depreciation of each individual component.

$$Total\ System\ Cost\ per\ year = Item_1\ Cost\ per\ year\ + Item_2\ Cost\ per\ year\ + \ldots$$

$$Total\ System\ Cost\ per\ year = \frac{I_1\ Cost}{I_1\ Lifespan} + \frac{I_2\ Cost}{I_2\ Lifespan} + \ldots$$

At a minimum, we should include the costs of our panels and batteries. A standard assumption is that panels have a lifespan of 20 years. Battery lifespans vary greatly depending on the technology used, but a typical assumption is that lead acid batteries can have a lifespan of 5 – 10 years.

Additional components costs can also be included to increase the detail of the calculation, such as costs for wiring, charge controller, inverter costs, or mounting racks.

We can also include non-technical costs, such as costs for installation, overhead, and financing. These costs often make up a large percentage of the costs incurred by the customer, but unlike components they do not have a physical lifespan. For these costs, there are two methods that we can use to calculate how their contribution toward the system costs on an annual basis.

Method 1: Treat the non-technical costs as if they were physical assets with a useful lifespan equal to the length of time before they are incurred again. For example, if a margin is added to a product on the sale, give that margin a lifespan of the time it takes until the next sale to that customer.

Method 2: If the non-technical costs are proportional to the system costs, then we need to increase the component costs by multiplying them by a factor. For example, if we assume that we sell systems at 50% higher than the material costs, then we multiply all of our component costs by 150%.

$$Total\ System\ Cost\ per\ year = Component\ Costs\ per\ Year \times (1 + Markup)$$

Aside: Selecting Conservative Timeframes for Depreciating Assets

For mature businesses and investors, it is reasonable to depreciate a piece of equipment over its full, expected lifespan. But being conservative in our estimates can be beneficial and it is worth considering why we might model the lifespan of our systems to be less than what they actually are.

One reason to make conservative estimates is that users do not always have the capacity to make full use of an asset for its entire lifespan, or else are not able to recover the residual value past a certain point. While a solar panel might have a productive 20 years in the hands of a utility company, a real life user might stop using their panel after 6 years if their battery dies and they run out of capital to replace it.

On a similar note, users may lack the confidence to take on longer-term investments and instead assess a solar system purchase as if it were a short-term investment. For example, a user who receives financing for three years to buy a solar system and mill might expect that the system be paid off completely after the financing period ends.

Step 2: Calculating the Total Energy Used Per Year

Once we have determined our annual system costs, we need to calculate how much energy is used. This is done using assumptions similar to those used in our modeling approach. To begin, we should first calculate the energy used in a single day.

$$Total\ Energy\ Used\ per\ Day = \ Power \times Hours\ Used\ per\ Day$$

Following this, we can now calculate the energy consumption in a year by multiplying by the energy used per day by the number of days used per year.

$$Total\ Energy\ Used\ per\ Year = \ Total\ Energy\ Used\ per\ Day \times Days\ Used\ per\ Year$$

Step 3: Calculating the Costs of Energy

Now that we have calculated our costs per year and our energy usage per year, we can calculate our cost of energy by plugging our answers into equation 2.

$$Cost\ of\ Energy = \frac{Total\ System\ Cost\ per\ year}{Total\ Energy\ Used\ per\ year}$$

A3: CALCULATING COSTS OF NEW SYSTEMS

The method given in Annex 2 is useful if we already have a solar system designed. But since most of the products that we consider in this research are new, it is highly likely that we do not have a well-dimensioned system with pricing information readily available on hand.

This section provides guidance on what can be done in this situation.

Use the Assumptions in This Paper

In this paper we provide three figures for the cost of energy based on industry benchmarks. Rather than go through the trouble of doing everything from scratch, we recommend that you start with these.

Use an Online Calculator

Another simple method is to use an online tool to calculate the system size. We recommend using the Cost of Reliability Calculator by Lee and Callaway, found here: https://emac.berkeley.edu/reliability.[2]

Tools like this greatly simplify these kinds of calculations, while also allowing for considerations such as usage patterns, location, and system reliability. Even better, this particular Cost of Reliability Calculator calculates the cost of energy for the system it recommends.

Use the Cost of Electricity from a Similar System

Another option is to calculate the cost of energy from an existing system and use this figure in your other calculations. For example, maybe you sell a solar system to power a water pump and has 1kW of panel power. You can calculate the cost of energy for that system and use this throughout your modeling. Even though a 2kW might cost more, it also produces more energy, and this ratio of cost per energy will remain roughly proportional in similar sized systems.

The advantage to this method is that it can reflect costs that often get left out of desktop calculations. There is often a disconnect between what is possible and what happens on the ground, and this method can capture those.

The disadvantage to this method is that not all costs scale proportionally with the system size. We don't recommend calculating the cost of energy in a solar lantern and then using this figure modeling a large-scale system.

Dimension a New System

It is tempting to plan out a new system from scratch, but we advise against this approach in the context of this paper, especially for laypeople. The purpose of our modeling approach is to be flexible, rapid, and give directional answers rather than highly precise answers. A rough approximation made by dimensioning a new system is unlikely to be more accurate than a rough approximation achieved through any other, simpler method; meanwhile, a highly precise calculation is unlikely to produce a more informative modeling outcome without similarly rigorous data sources for all other assumptions used in the modeling.

A4: PRACTICAL EXAMPLES

Example 1: Cost of Energy Based on a Similar System

Super-Duper Solar Co. sells productive-use appliances with stand-alone systems. Their flagship product is a solar water pump that they sell with a solar system that uses 200W solar panels, 100Ah lead acid batteries, an inverter, and charge controller. For their water pump system, their system is as follows:

Component	Lifespan	Cost	Amount	Total Cost
200W Panel	20 years	$90	10	$900
12V 100Ah Battery	5 years	$250	4	$1000
Inverter	5 years	$500	1	$500
Charge Controller	5 years	$400	1	$400
TOTAL COST				$2800
System Sales Price				$4000
Margin				$1200

Super-Duper Solar is interested in understanding the market for a solar-powered milling machine. They decide to estimate the cost of energy for a mill by calculating the cost of energy of their solar water pump system.

Step 1: Calculate the System Cost per Year

Super-Duper Solar first calculates the total system cost per year by calculating the component costs per year. Since the company expects their customer to replace their system after 5 years, they estimate its lifespan as 5 years.

$$Total\ System\ Cost\ per\ year = \frac{\$900}{20\text{ years}} + \frac{\$1000}{5\text{ years}} + \frac{\$500}{5\text{ years}} + \frac{\$400}{5\text{ years}} + \frac{\$1200}{5\text{ years}}$$

$$Total\ System\ Cost\ per\ Year = {}^{\$665}/_{\text{year}}$$

Step 2: Calculate the System Cost

Next, Super-Duper Solar estimates the total energy used per year. They estimate that the 1kW mill will get used 6 hours per day, 300 days per year.

$$Total\ Energy\ per\ year = \left(1\text{kW} \times {}^{6\text{h}}/_{\text{day}}\right) \times {}^{300\text{ days}}/_{\text{year}} = {}^{1800\text{ kWh}}/_{\text{year}}$$

Step 3: Calculate the Cost of Energy

Finally, Super-Duper solar calculates the cost of energy for this system.

$$Cost\ of\ Energy = \frac{{}^{\$665}/_{\text{year}}}{{}^{1800\text{ kWh}}/_{\text{year}}} = {}^{\$0.37}/_{\text{kWh}}$$

Example 2: Cost of Energy for Financed Product Using Online Calculator

GR8-Loans is a NGO that supports local cooperatives in Kenya with asset financing for products that improve their livelihoods. Their cooperatives have expressed interest in having a rice hulling machine that they found in town, which uses a 500W motor. They are interested in providing this kind of product with solar-power products to their groups, but most of their expertise is in community engagement, not engineering. They decide to use the online Cost of Reliability Calculator to help them plan their system.

Step 1: Calculate System Size

After speaking with their cooperatives, GR8-Loans learns that their cooperatives expect their rice hulling machine to be used 5 days per week, 4 hours per day, and mostly in the evenings. They calculate the daily energy consumption for their system.

$$Total\ Energy\ per\ day = \left(0.5\text{kW} \times {}^{4}/_{\text{day}}\right) = {}^{2\ \text{kWh}}/_{\text{day}}$$

Next, they locate the online Cost of Reliability calculator. They decide that a 95% reliability would be good, and that the "Representative" daily load profile is the closest to matching their cooperatives usage. They input the following into the Calculator and leave all other settings at the default:

Target Reliability: 95%
Daily Load: 2kWh/day
Peak Capacity: 0.5kW
Daily Load Profile: Representative

After inputting the settings, they update the map and find the coordinates for their cooperative location on the map. When they hover over the map, they read out that their system should have 0.45kW of panel power and 0.92kWh of storage.

Step 2: Find the System Component Cost

GR8-Loans decides to get quotations for their components. From the calculator, they know they need at least 450W of panel power. For their batteries, they need calculate the size. They assume they will use a 12V lead acid battery. They speak with their local supply store, who tell them that most lead acid batteries get discharged to 50% of their capacity.

$$Battery\ Size = \frac{Energy\ Stored}{Voltage \times Depth\ of\ Discharge} = \frac{920\text{Wh}}{12\text{V} \times 50\%} = 153\text{Ah}$$

After calculating their battery size, they get quotations for each of the components. Their supply shop recommends using two 75Ah batteries and also recommends a charge controller and inverter based on their requirements. They use this to calculate the total system cost, and then add a 20% cost to it, which covers the cost of financing over the 3 year period.

Component	Lifespan	Cost	Amount	Total Cost
250W Panel	20 years	$150	2	$300
12V 150Ah Battery	5 years	$500	1	$500
Inverter	5 years	$500	1	$500
Charge Controller	5 years	$400	1	$400
TOTAL COST				$1700
Financing Cost (20%)				$340
TOTAL SYSTEM COST				$2040

Step 3: Calculate Costs per Year

Now that GR8-Loans knows how much their system costs, they calculate the annual cost. Although each of the components lasts 5-20 years, they want their cooperatives to have earned back their money within the financing period of 3 years.

$$Total\ System\ Cost\ per\ year = \frac{\$300}{3\text{ years}} + \frac{\$500}{3\text{ years}} + \frac{\$500}{3\text{ years}} + \frac{\$400}{3\text{ years}} + \frac{\$340}{3\text{ years}} = \frac{\$2040}{3\text{ years}}$$

$$Total\ System\ Cost\ per\ year = {}^{\$680}/_{\text{year}}$$

Step 4: Calculate Usage per Year

GR8-Loans now calculates the annual usage based on their cooperative's daily usage. Since they assume the rice huller will be used 5 days per week, they expect it to run 260 days per year.

$$Total\ Energy\ per\ year = \left({}^{2\text{ kWh}}/_{\text{day}}\right) \times {}^{260\text{ days}}/_{\text{year}} = {}^{520\text{ kWh}}/_{\text{year}}$$

Step 5: Find the Cost of Energy

Finally, GR8-Loans finds the Cost of Energy for the system over the financing period.

$$Cost\ of\ Energy = \frac{{}^{\$680}/_{\text{year}}}{{}^{520\text{ kWh}}/_{\text{year}}} = {}^{\$1.31}/_{\text{kWh}}$$

When using this price in their model, they realize their rice hulling machine isn't going to pay itself off within the 3-year period. They decide to extend the financing period to 5 years, and find that the cost of energy consequently drops to \$0.78/kWh and the hulling machine can recover the costs.

ACCESS TO ENERGY INSTITUTE

Access to Energy gGmbH (A2EI)
Paul-Lincke-Ufer 8d
10999 Berlin, Germany

info@a2ei.org | www.a2ei.org