NIGERIA POWER SECTOR PROGRAM
AGRICULTURAL PRODUCTIVE USE STIMULATION IN NIGERIA: VALUE CHAIN & MINI-GRID FEASIBILITY STUDY

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Cover Photo: Power Africa-Nigeria Power Sector Program

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ACRONYMS

Acronym or Symbol	Definition
A4T	A4&T Power Solutions
ADPs	Agricultural Development Programmes
AMEFAN	Association for Nigerian Fabricators
APPEALS	Agro-Processing Productivity Enhancement and Livelihood Improvement Support Program
°C	Celsius degrees
CNSL	Cashew Nut Shell Liquid
DBN	Development Bank of Nigeria
BOI	Bank of Industry
BnS	Buy and sell modality where processors buy raw materials and sell processed goods
CARI	GIZ Competitive African Rice Initiative
FADAMA	National Fadama Development Project in Nigeria by World Bank
FAO	Food and Agriculture Organization of the United Nations
FCMB	First City Monument Bank
FFS	Fee-for-service modality where processors charge a fee for processing service
FIIRO	Federal Institute of Industrial Research
GEEP	Bank of Industry's Government Enterprise and Empowerment Program
GVE	Green Village Electricity
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ha	Hectare
HP	Horsepower
IFC	International Finance Corporation
IFPRI	International Food Policy Research Institute
IRR	Internal rate of return
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt-hour
l	Liter
LAPO	LAPO Microfinance Bank LTD
MAS	Mini-grid Acceleration Scheme
mm	Millimeter
MSME	Micro, Small, and Medium Enterprises
NCAM	National Center for Agricultural Mechanization
NPV	Net present value
NEP	National Electrification Programme
NIRSAL	Nigeria Incentive-Based Risk Sharing System
NSIA	National Sovereign Investment Authority
PA-NPSP	USAID's Power Africa Nigeria Power Sector Program
PFI	Private Financial Institution
PV	Solar photovoltaics
REA	Nigerian Rural Electrification Agency
REF	Nigerian Rural Electrification Fund
t	Metric tons (1000 kilograms)
USDA	United States Department of Agriculture

EXECUTIVE SUMMARY

Electrifying agricultural productive uses is critical to enabling sustainable, commercially-led electricity service provision in un- and under-served rural communities in Nigeria. Agricultural activities are the bedrock of the local economies in these communities, and yet, agriculture and electricity actors rarely coordinate to understand which agricultural activities to electrify (and where) to generate win-win opportunities for both sectors. Many commercial electricity providers lack the content knowledge and financial resources required to support productive uses. As a result, most investments in rural electrification are not accompanied by a surge of income-generating activity. This study conducted by the Power Africa Nigeria Power Sector Program (PA-NPSP) identifies current opportunities to electrify agricultural productive uses, how these opportunities can be developed through commercial business models, and the strategies stakeholders can use to overcome barriers to deployment.

REDUCING COST AND INCREASING REVENUE THROUGH AGRICULTURAL ELECTRIFICATION

Despite geographic differences and a wide range of crops under cultivation, there are immediate opportunities to electrify fossil-fueled and manual processing activities for several agricultural value chains in rural Nigerian communities. These opportunities are commercially-viable for processors, who can reduce costs and increase revenue, and are beneficial for mini-grid economics.[i]

This study considered 12 crop value chains across Nigeria's Kaduna and Cross River states, including more than 250 field interviews with farmers, processors, and traders in over 40 rural communities as well as an extensive literature review and interviews with sector experts (see **Appendix A** for detailed data). Based on this data collection, value chain activities with electrification potential for each crop were evaluated across four dimensions: existing local capacity for the activity, presence of a market for the product, availability of electric processing equipment in Nigeria, and scalability of the activity. Considering these factors, prospective productive use activities can be divided into three tiers based on their readiness for electrification and implementation. **Figure 1** shows this prioritization into: *Tier 1*, indicating immediate readiness for deployment; *Tier 2*, indicating strong medium-term potential with support to overcome one or more barriers, and; *Tier 3*, indicating longer-term potential if additional barriers are addressed. **Section 3** describes this analysis in greater detail, and **Appendix A** includes a thorough review of individual crops and their associated activities.

Ishaq Haruna running his 22 horsepower diesel flour mill in Kadage, Kaduna state. Mr. Haruna spends $4.40 US per day on diesel to run his mill compared to an estimated $1.80 he'd spend on electricity from a mini-grid with a $0.60/kWh tariff.

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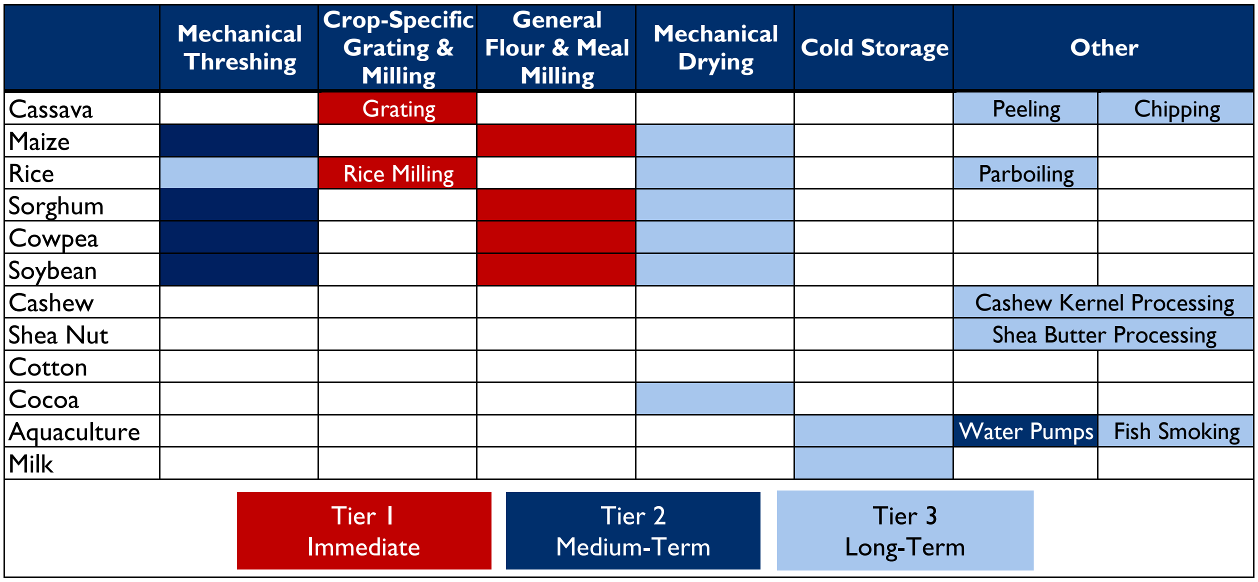
[i] While this study focuses on electrification using mini-grids, the findings are applicable to a variety of electricity access technologies (e.g., solar home systems, grid extension, etc.).

Figure 1: Summary of Tier Classifications for Value Chain Activities Across 12 Crops Analyzed in the Study



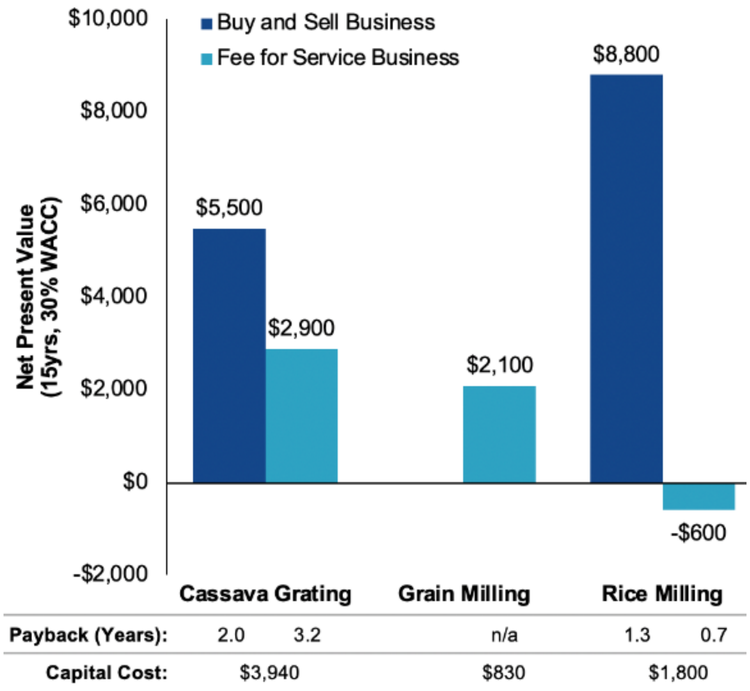
	Mechanical Threshing	Crop-Specific Grating & Milling	General Flour & Meal Milling	Mechanical Drying	Cold Storage	Other	
Cassava		🟥 Grating				▨ Peeling	▨ Chipping
Maize	🟦		🟥	▨			
Rice	▨	🟥 Rice Milling		▨		▨ Parboiling	
Sorghum	🟦		🟥	▨			
Cowpea	🟦		🟥	▨			
Soybean	🟦		🟥	▨			
Cashew						▨ Cashew Kernel Processing	
Shea Nut						▨ Shea Butter Processing	
Cotton							
Cocoa				▨			
Aquaculture					▨	▨ Water Pumps	▨ Fish Smoking
Milk					▨		

🟥 Tier 1 Immediate
🟦 Tier 2 Medium-Term
▨ Tier 3 Long-Term

From this analysis, there are three clear Tier 1 activities primed for electrification and implementation in Nigeria immediately. Cassava grating, rice milling, and flour milling (across several grains) all have strong fundamental characteristics indicating that electrifying them can be straightforward and successful. This is confirmed by analysis of the economic value proposition of electrification—for these priority value chains and activities, electric processing equipment powered by a mini-grid enables processors to save on operating costs and can even increase revenue compared with existing fossil-powered equipment (**Section 4**).

As Figure 2 shows, depending on the sales approach the processor uses—either buying raw material and selling the processed product (BnS), or a fee-for-service (FFS) model in which they process material for others—payback on the electric processing equipment is possible in three years or less. FFS rice milling is an exception, where current fees charged by millers would need to be increased to reflect the improved rice milling yields that FFS customers would receive from upgraded mills in order to recoup the capital cost of new equipment. As detailed in **Section 4**, electrifying any one of these activities in a community would also improve a mini-grid's economics, reducing tariffs by **8–14**%. Electrifying all three activities in a community could reduce tariffs by **26**%.

Figure 2: Comparison of Cash Flow Analyses for Electrification of Tier 1 Processing Activities

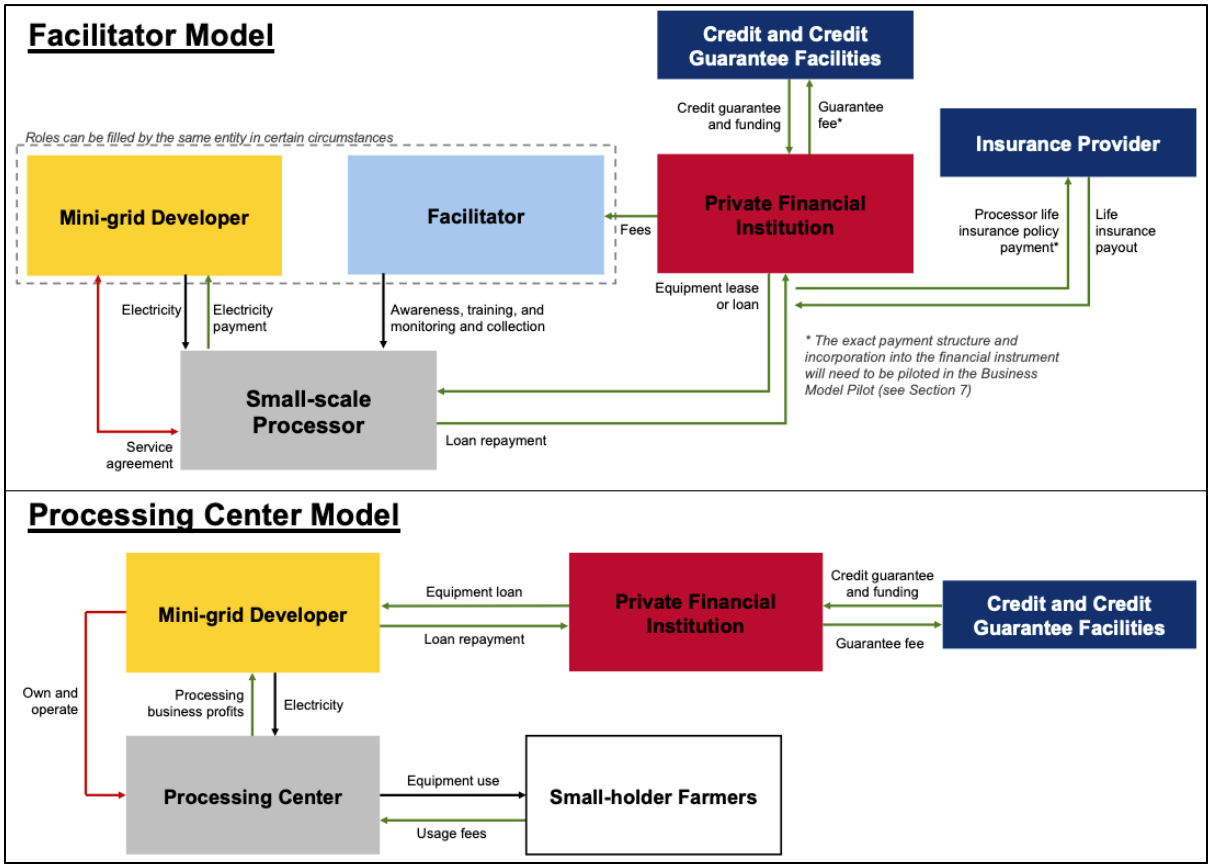


TWO COMMERCIAL BUSINESS MODELS CAN ADDRESS BARRIERS TO IMPLEMENTATION

This report proposes a **Facilitator Model** and a **Processing Center Model** as business models which address five major barriers to electrifying agricultural productive uses at scale in Nigeria:

1. **Lack of access to credit for equipment purchase** often prevents small-scale processors and mini-grid developers from obtaining new machinery. These actors lack the credit history and collateral to obtain financing with reasonable terms—all but one of the small-scale processors surveyed identified access to credit as the main barrier limiting their ability to grow their processing capacity, and neither microfinance institutions nor commercial bank agents were active in the rural communities surveyed.
2. **Lack of reliable electricity** in rural communities to operate equipment limits adoption, as most small-scale processors surveyed identified access to reliable electricity as the second most important barrier they face.
3. **Lack of awareness and education for would-be equipment purchasers** prevents them from seizing opportunities to invest in electric productive use equipment—over 80% of survey respondents in mini-grid-appropriate communities indicated it was difficult or very difficult to access extension or business development services.
4. **Lack of market access** limits the ability of local actors to sell new products made possible by mechanization, or to receive premium prices for higher-quality commodities. Absence of formal off-take agreements increases the revenue risk perceived by lenders.
5. **Lack of access to electric equipment** which is not always evaluated alongside the development of mini-grid systems and only considered after operations begin, which means electricity is available but electric agricultural processing equipment may not be.

Figure 3: Institutional Arrangements of The Facilitator and Processing Center Business Models



The **Facilitator Model** and **Processing Center Model** provide the necessary structure and support to overcome these barriers and enable the productive use of electricity in agriculture.[ii] Both models are described in **Section 4**. As shown in **Figure 3,** the Facilitator Model is led by a facilitator who enables small-scale processors to invest in equipment by educating processors and linking them with finance providers who make an equipment loan (or lease) to the processor. While the small-scale processor is ultimately responsible for the credit and operational risk, the facilitator builds awareness about the investment opportunity and provides business development training to support loan applications and equipment selection. The Facilitator Model avoids displacing incumbent processors, which are common for Tier 1 activities.

In the Processing Center Model, a mini-grid developer purchases, owns, and operates the equipment for a new processing service that existing entrepreneurs are not able to provide. The mini-grid developer then either charges the farmers a fee to use the equipment or sells the processed product to an offtaker. The Processing Center Model is appropriate for activities where there is proven demand for a product, but the processing activity is not commonly mechanized in local communities. This applies to activities that pre-process or conserve the quality of the crop, but where investment is a barrier to entry for small-scale processors. Examples include Tier 2 activities such as threshing. A centralized, multi-crop, electric thresher can provide mechanical threshing and cleaning for a variety of cereals (**Appendix A.1.1**). Using the Processing Center Model ensures capacity utilization and reduces the total investment compared to several independent processors providing the service.

FACILITATING LENDING AND DE-RISKING INVESTMENTS THROUGH A DEPLOYMENT STRATEGY

Both commercial business models depend on linkages with financial institutions willing to lend in the small-scale agriculture space. However, many financiers perceive investments in small-scale agricultural processing to be relatively high risk. To de-risk these investments, agricultural development and electricity access programs and agencies can facilitate connections to several different financial institutions through the deployment strategy presented in **Section 6.**

The objective of this deployment strategy is to stimulate investment in productive uses of electricity by connecting financial institutions with existing electrification and agriculture programs. Without targeted efforts to facilitate these connections, they will likely be slow to materialize and hinder the implementation of productive use business models. The model focuses on unlocking commercial finance while incorporating guarantees to de-risk investment and reduce the blended cost of capital so that small-scale processors can afford equipment purchases. Specifically, a **credit facility, credit guarantee facility, and insurance provider** provide credit lines, credit risk guarantees, life insurance respectively, to unlock loans from **private financial institutions**. Meanwhile a **grant facility** provides grant financing and technical assistance to reduce the blended cost of capital and fund the pre-investment stage, with verification by an **independent verification agency**. Depending on the business model being used, these funding flows then pass to either the **small-scale processor** or **mini-grid developer** for equipment purchase.

[ii] A third model, the **Offtaker-Based Model**, involves an offtaker investing in processing in rural communities and then sourcing crops from surrounding communities. However, this model is relatively complex and not appropriate for the Tier 1 and Tier 2 activities identified in the study. It is described further in **Appendix D.3**.

A CLEAR ROADMAP TO ENABLE IMPLEMENTATION AT SCALE

This study provides a clear roadmap to put the recommended agricultural productive use business models and deployment strategy into action. Because these models include significant private sector participation to ensure long-term sustainability, jumpstarting deployment will require proof points showing financial returns on equipment investment and demonstrated business model feasibility to de-risk and attract private investment.

The roadmap shown in delivers these proof points through a combination of cross-sectoral engagement across the agriculture and electricity sectors alongside a series of pilots to test the findings and approaches identified in this study. There are five key steps in the roadmap, which is described fully in **Section 7**:

1. **Convene a working group across the agriculture and energy sectors** to coordinate, guide, and promote near-term activities required to achieve long-term commercial viability.
2. Implement **phase-one pilots to test equipment** for Tier 1 activities and collect operational data to refine financial models.
3. Use phase-one pilot data to design and implement **phase-two pilots to test recommended commercial business models** and develop financial instruments, partially in parallel with equipment pilots.
4. Use the lessons learned from both pilots to refine and implement the deployment strategy, formalizing the structures needed to **finance and support widescale equipment rollout for Tier 1 activities in mini-grid projects**.
5. In parallel with deployment of Tier 1 activities, begin addressing identified barriers to Tier 2 and 3 opportunities in partnership with working group stakeholders.

The prospects for electrification in Nigeria have never been brighter. With dramatic cost reductions in sight, and increased attention from government, development partners, and the private sector, energy access technologies are poised to proliferate at breakneck speed. However, it is critical that these projects are accompanied by business models that electrify agricultural productive uses—failing to do so may compromise project economics and longevity. Pairing productive use and rural electrification with an effective deployment strategy will unlock local economic development and can serve as a springboard toward realizing the full potential of rural electrification.

1 INTRODUCTION

Electrifying agricultural productive uses is critical to enable sustainable, commercially-led electricity service provision in un- and under-served rural communities in Nigeria. Across off-grid and on-grid electrification, providing electricity is a means to enable the economic activities that use power to generate income. Agricultural activities are the bedrock of most rural economies—as goes agriculture, so goes community economic development. Yet, agriculture and electricity actors rarely coordinate to understand which agricultural activities should be electrified to generate win-win opportunities for both sectors. Many commercial electricity providers lack the content knowledge and financial resources required to support productive uses. As a result, most investments in rural electrification today are not accompanied by a surge in income-generating activity. This study by the Nigeria Power Sector Program, implemented by Deloitte Consulting LLP through a subcontract with Rocky Mountain Institute, identifies win-win opportunities to electrify agricultural productive uses today, how they can be developed through commercial business models, and the tools stakeholders can use to overcome barriers to deployment.

The main body of the report summarizes the study and a series of appendices provide much greater depth of analysis, data, and recommendations for policymakers and program implementers to explore.

- **Section 2: Study Scope and Data Collection Approach** provides context on the geographic and topical scope of the research and the approach to data collection.
- **Section 3: Value Chain Analysis** presents an overview of the 12 agricultural value chains included in the study along with the methodology used to prioritize them, and which 'Tier 1' activities in the value chains are immediately ready for electrification and implementation at scale. The companion **Appendix A**. presents an in-depth analysis of all value chains and full assessment of electrification opportunities, while **Appendix B** presents a sample of existing equipment vendors for Tier 1 activities in Nigeria that can be built on to further map equipment availability.
- **Section 4: Economic Viability of Electrifying Processing Activities** evaluates Tier 1 activities from a small-scale processor perspective and a mini-grid perspective. The companion **Appendix C** presents further economic analysis along with the methodology and assumptions used to prepare the financial models.
- **Section 5: Business Model Options** describes the key barriers preventing purchase of electric equipment and the two business models suitable to address them for priority activities. The companion **Appendix D** provides further detail on these business models, assessing roles and responsibilities and how the models address key barriers. It also identifies a third model suitable for specific activities in the future.
- **Section 6: Recommended Deployment Strategy and Financial Implications** identifies an approach to providing finance and support for business model implementation, and the institutional arrangements needed to do so. The companion **Appendix E** explains the type and amount of financing required by this strategy, along with the methodology and assumptions used to estimate the funding required. **Appendix F** presents a streamlined mapping of key actors active in the agricultural and energy sectors in Nigeria, which informed recommended institutional arrangements.
- **Section 7: Recommendations for Actions** provides a clear roadmap of steps needed to put this study's findings and recommendations into practice, toward a future where all commercially-led electrification projects in rural areas are developed to effectively stimulate agricultural productive use.

2 STUDY SCOPE AND DATA COLLECTION APPROACH

This study investigates opportunities for productive use of mini-grid electricity in Nigerian agriculture. Previous high-level reports have identified numerous possible applications of mini-grid electricity in the electrical sector across sub-Saharan Africa.[1,2] To stimulate these productive uses, the mini-grid sector must understand which specific activities are appropriate for rural off-grid contexts, identify barriers to implementation, and design solutions to overcome them. This study applies value chain and technoeconomic analysis to discover which potential productive use opportunities are suitable for rural Nigerian mini-grids and entrepreneurs. Although the specific focus is limited to mini-grids, many of these findings are also relevant to solar home system and utility-scale electricity. This section defines the scope of the research and the approach to data collection in rural communities.

2.1 STUDY SCOPE

The study focuses on twelve prominent agricultural value chains in Nigeria's Cross River and Kaduna states. **Table 1** shows the crops included in the study along with the states in which field studies observed them. These crops were selected based on their prevalence in rural Nigerian communities appropriate for mini-grids, and the potential for steps in their value chains to be electrified. Cross River and Kaduna states were selected as focus geographies given their representativeness across broad swathes of Nigeria. **Figure 4** shows the location of communities surveyed in these states, which cover Nigeria's two most prevalent agroecological zones: tropical semi-arid and tropical sub-humid environments.[3, iii] The tropical semi-arid zone in Kaduna is naturally suited to water-efficient, heat-tolerant crops like maize, sorghum and cowpea. Cross River's wetter climate enables less drought-tolerant plants such as cocoa to thrive. Rice can be grown in both contexts, especially when irrigation is available via fadama aquifers, natural sources, or pumped groundwater.[4]

Table 1: Value Chains Included in This Study and Observed Coverage Between Two Target States

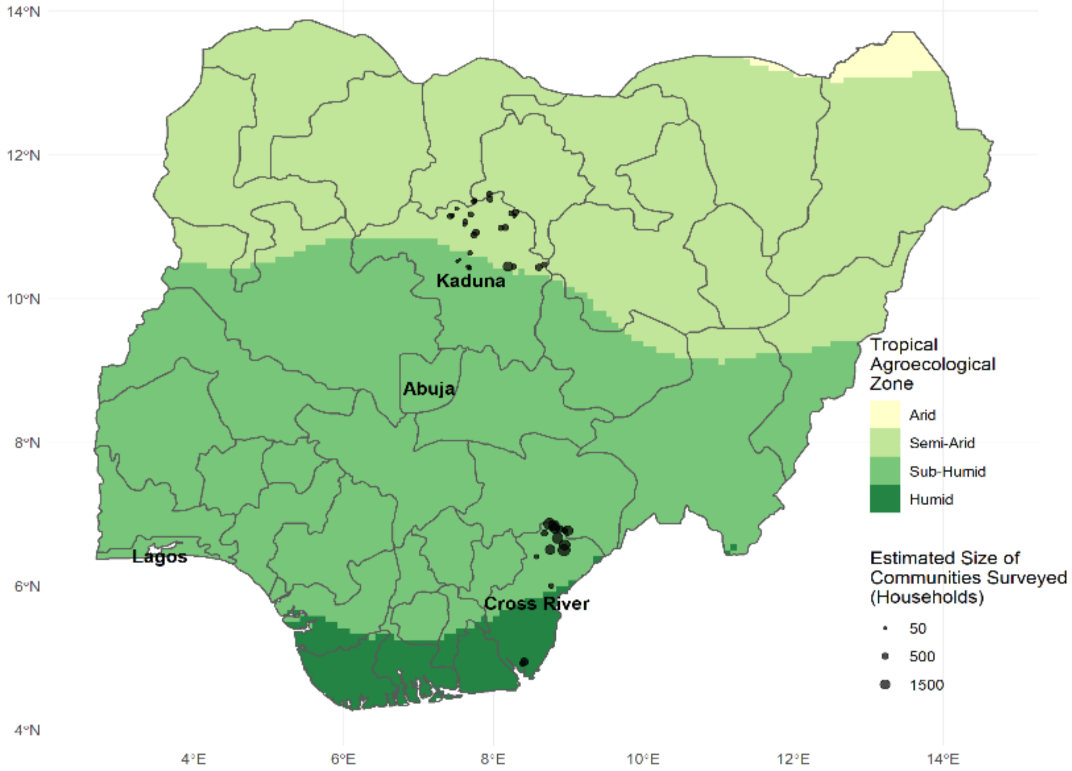
Value Chain	Kaduna	Cross River
Aquaculture		✓
Cashew		✓
Cassava		✓
Cocoa		✓
Cotton	✓	✓
Cowpea	✓	✓
Maize	✓	✓
Milk	✓	
Rice	✓	✓
Shea Nut	✓	
Sorghum	✓	
Soybean	✓	✓

For each target value chain, this study assesses opportunities for electrification that are viable for both mini-grid companies and local agro-entrepreneurs. To support this analysis, data was collected across the following value chain characteristics:

- **Crop characteristics and background,** including how the crop is farmed, the local yields, whether production is seasonal, and where cultivation is conducted.
- **Market status and trends,** particularly in what form the end products are consumed locally, and by whom, whether local markets are robust, and whether demand is growing.
- **Value chain activities,** focusing on the key steps between harvest and consumption, which value chain paths are most prominent, who participates in processing, and which crops or intermediate products face post-harvest losses.
- **Productive use opportunities,** identifying process steps best suited for electrification.

[iii] Each of these environments experience distinct wet and dry seasons, with most rain falling roughly June through September. In Nigeria, annual rainfall decreases from south to north, from over 2,000 mm/year on the tropical coast to 500 mm/year in the northeast.[4]

Figure 4: Map of Nigeria's Tropical Agroecological Zones with Communities Surveyed in Kaduna And Cross River



2.2 DATA COLLECTION APPROACH

To provide actionable recommendations, this study performed a comprehensive data collection exercise, both reviewing existing information and collecting new data. Data was collected in three ways:

- **Field Surveys:** To thoroughly understand the on-ground realities of local communities, field surveys were conducted in both Kaduna and Cross River states. Data were collected in 41 communities across these states, from November 2019 through January 2020. **264** field interviews were conducted in collaboration with Sahel Consulting by four local agricultural enumerators utilizing the Survey Solutions tablet-based interviewing tool.[iv] Further details are included below in **Section 2.1**.
- **Literature Review:** Rather than recreate existing information, this study was designed to build on the current knowledge base around agriculture and productive use electrification to develop new insight into how to deploy these solutions in Nigeria. To this end, an exhaustive review of available literature was performed, including **190** primary literature sources; **Appendix G** presents a full bibliography.
- **Expert Interviews:** To further build on existing knowledge and efforts, and to ensure that study findings and recommendations are practical, over **50** organizations in Nigeria across the energy and agriculture sectors, including private sector companies, non-governmental organizations, development partners, financial institutions, and government agencies, were interviewed and asked for feedback.

[iv] Survey Solutions is a free computer-assisted personal interviewing tool developed by the World Bank. This platform was used to conduct, monitor, and analyze offline digital interviews with local value chain actors.

2.2.1 *Field Survey Details*

Field surveys were critical to the ground-truth analysis of agricultural value chains in rural Nigeria. PA-NPSP designed an extensive survey questionnaire targeted at four types of value chain actors: community champions, farmers, agricultural processors, and agricultural traders.[v] **Table 2** shows a count of the interviews conducted and along with example questions for each respondent class. These interviews were on average just under an hour in length per respondent. The full questionnaire is included in **Appendix H.**

A survey enumerator for this study, Sylvanus Orewa, interviews Abdulmalik Gambo, a cassava and rice farmer.

Given this study's focus on mini-grids, it was important that data was collected in communities representative of prospective mini-grid sites. Working with local enumerators in Kaduna and Cross River states, PA-NPSP identified locations that fit criteria for mini-grid-suitable communities**.** Surveys focused on off-grid communities with suitable size and density for mini-grid service with above-average local economic activity and infrastructure. Key characteristics of surveyed communities included:

- **Size:** Communities had a median size of 375 households and maximum of 2,500 households.
- **Infrastructure:** 90 percent of the communities had cell phone service, and enumerators prioritized communities with roads that would be passable by vehicles carrying agricultural products and mini-grid components.[vi]

Table 2: Field Survey Interview Tallies and Sample Questions

Respondent Type	n	Sample Questions
Community Champion	42	• Which crops are produced by more than five farmers in this community? • In a typical day, which power sources do you use? • Which processing activities are conducted in this community? Which are mechanized?
Agricultural Processor	50	For a given processing activity: • What is the energy source and engine size, if applicable? • What are the operating costs for this equipment? • What is the gender of the operator?
Farmer	115	For a given crop: • What are seasonal yields? • In what form, at what price, and to whom is the crop sold? • What is the demand for mechanical threshing and drying?
Agricultural Trader	57	For a given commodity: • What is the quantity, price and point of sales? • What are major points of post-harvest loss?
Total	**264**	

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[v] Community champions are defined as leaders or representatives of a community who know the community well and are able to provide high-level information about local residents, issues, and economies.

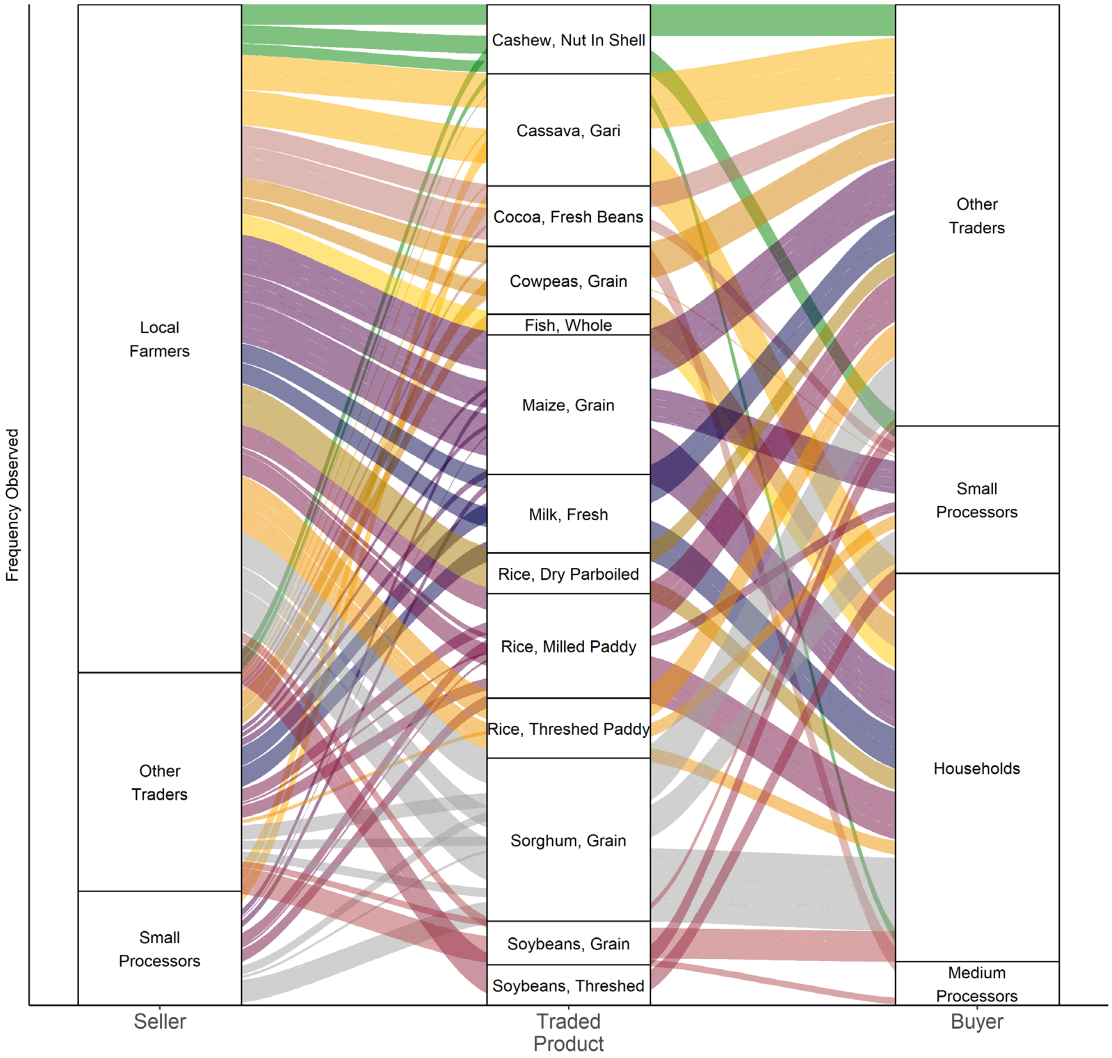
[vi] In communities with cell phone service, 65% had SMS/voice access only and an additional 25% could access at least some data service.

- **Energy access and satisfaction:** No surveyed communities had grid access, or had dilapidated grid equipment (e.g., transformers or relic distribution poles) but had not received any grid electricity in over 6 months. 35 percent of respondents cited access to electricity as their top development priority, and 92 percent of respondents included it in their top three. One hundred percent of community champions reported that their communities were either unsatisfied or very unsatisfied with their energy access.
- **Generator and solar home system ownership:** Community champions in Cross River reported that an average of 5 in 10 households utilized a generator, versus an average of 3 in 10 in Kaduna. In contrast, solar home system use was very rare in Cross River but community champions in Kaduna reported use among 3 in 10 households.

2.2.2 Trade Patterns Identified

The results of the study's field surveys are referenced throughout this report and summarized in the value chain analysis presented in **Section 3** and **Appendix A**. The data collected also provides a clear overview of the movement of goods from seller to buyer across the 12 crops, as shown **in Figure 5**.

Figure 5: Alluvial Plot of Purchases and Sales by Local Traders Interviewed in the Field Survey



Flow size is proportional to the likelihood of a trade from a source to final buyer.

Each flow in this diagram represents movement of a product by a middleperson who purchases the good from farmers, processors, or other traders, and then sells to the next level along the value chain, including processors, households, or still other traders. For example, the topmost flows (green) show that cashews are traded as whole nuts which are nearly always bought from local farmers and sold on to other traders or local processors. Local farmers are the dominate primary sellers, with other traders and local households as the primary buyers. Though some processing happens on either the buyer or seller side of these trade flows, many products are still traded as raw commodities. This is a clear indication of the potential for growth in local processing within mini-grid communities. These trade flows are discussed in detail for each value chain in **Appendix A.**

2.3 PRIORITIZATION METHODOLOGY

Across the 12 value chains included in this analysis, there are hundreds of possible combinations of crops and value chain activities to consider for electrification. The task of this study is to identify which of these activities are most promising for electrification and should be prioritized in productive use stimulation programs in the near-term.

2.3.1 Activity Evaluation Criteria

In the value chain analysis presented in **Section 3**, four criteria help rate productive use activities on a sliding scale from "deployment ready" to "significant support required". They include:

1. **Local Capacity**. Activities where local processors already possess the requisite knowledge and skill will be easier to electrify. If electrification of a value chain step requires significant deviation from typical processor practices then additional capacity building may be required to help processors adapt, and introducing new value-add operations is risky.[vii] Deployment-ready activities integrate into local processing operations without any significant re-training, and without risking low customer adoption of new "best practices" from outside groups.
2. **Offtake Market**. Deployment-ready productive use activities have strong local markets to sell the output of the value-add step. Because mini-grid communities may be isolated from peri-urban or urban markets, complex supply chain mechanisms are often required to deliver products to buyers outside of nearby rural areas. Potential returns from some value-add products may justify efforts to support market access but doing so requires extra investment and success is not guaranteed. Immediate opportunities for productive use are those that can sell their products to local community members or through pre-existing trade networks.
3. **Electric Equipment**. Productive use opportunities for which there is a mini-grid-compatible appliance available on the Nigerian market today will be significantly easier to quickly deploy than opportunities requiring equipment import or design. Using preexisting equipment

Otala Ibe is a rice miller in Cross River state. His old, single-stage mill removes rice bran but also breaks a large fraction of the kernel in the process. Replacing mills like his with electric, two-stage mills is rated "deployment-ready" for all criteria.

[vii] For examples, see **Appendix A**, particularly Box A.2 **in Appendix A.2** on high-quality cassava flour and **Appendix A.8** on cashew kernel production.

ensures that the equipment required to perform the processing is feasible to electrify and avoids complicating implementation programs by potentially costly development efforts. However, equipment piloting programs should be used to confirm appliance functionality with mini-grid infrastructure and ensure rural customer satisfaction with its performance (see **Section 7** for recommended next steps).

4. **Scalability**. An initial mini-grid productive use program will seek to benefit many communities over a broad geographical range. Productive use activities in value chains that are widespread and high-volume can be scaled more efficiently than niche or specialty products. Deployment-ready activities are likely to be replicable across thousands of Nigerian mini-grid sites. In contrast, activities that depend upon rare preconditions for success—such as the offtake agreements with commercial dairy processors required to warrant milk chilling operations, or preexisting clusters of shea parklands to fulfill semi-mechanized shea butter production—will require significant support to scale.

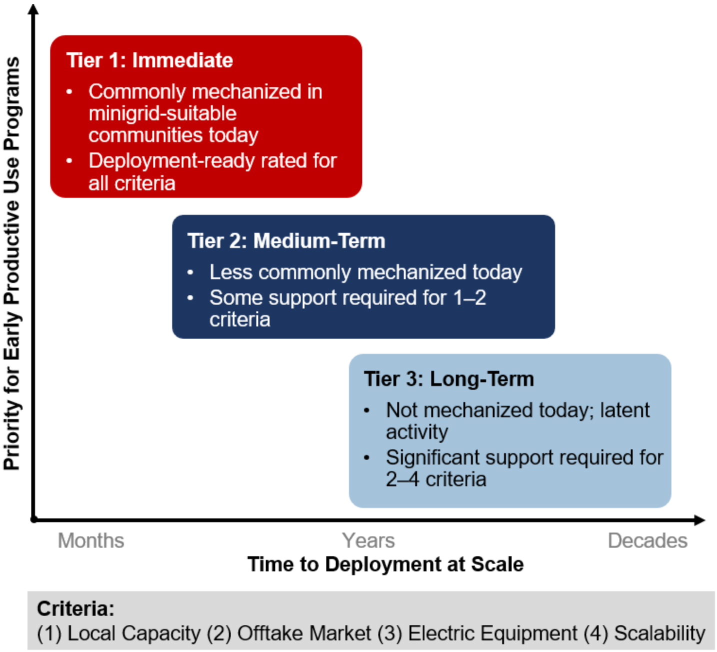
2.3.2 Ranking Activities by Tiers

Applying the four prioritization criteria defined above allows prospective productive use activities to be sorted into three tiers based on their readiness for electrification and implementation (**Figure 6**).

Tier 1: Immediate. These activities are viable for immediate electrification in a mini-grid context with minimal programmatic support beyond appliance financing and procurement. These activities begin with crops that are commonly produced in high volumes, and which are already commonly mechanically processed before sale into robust local markets. These are also the activities with the most robust appliance market, where mini-grid-compatible equipment is already available for purchase and pilot testing. Integrating these activities would improve mini-grid capacity utilization, as shown in **Section 4.2**, and after field-testing equipment it is recommended to incorporate them alongside all new mini-grid projects in communities that cultivate these staple crops.

Tier 2: Medium-Term. These activities are not far from being viable for electrification today but will require more program support than the *immediate* activities. Beyond just appliance financing, these supports may include enabling offtake, developing suitable appliances, or building local capacity. Tier 2 activities are not ready for immediate deployment in rural mini-grids but have significant potential given community acceptance of new practices, mini-grid-compatible electrical equipment, and robust market linkages for processed products. Although these hurdles are surmountable with proper support, the average mini-grid developer would not be likely to address them alone. These activities are recommended for consideration by larger electrification programs that can include this support, or for local entrepreneurs and off takers with special sector expertise.

Figure 6: Illustration of Tiers Utilized to Classify Productive Use Activities by Their Readiness for Electrification with Mini-Grids



Tier 3: Long-Term. These activities may have long-term potential for electrification, but significant support would be required to make mini-grid deployment economic and sustainable. This category includes the hundreds of latent agricultural processing activities that could conceivably utilize electricity but would require considerable effort to build adequate local capacity, market linkages, and supply of mini-grid-compatible equipment from the ground up. These are activities which are either rarely conducted in rural communities or are primarily conducted manually. Though incorporation of these activities into a mini-grid deployment program is not recommended today, many may be prime targets for study by agricultural development institutions or corporate actors interested in developing their local supply chains.

Ekpe Simon Egrinya in his rice field just off the road in Ugboro community, Cross River state. Receiving reliable power is his top development priority.

Mr. Egrinya farms five hectares of rice and manages two harvests per year using water channeled from nearby irrigation ditches. He is a member of the Young Farmers Cooperative, and he would like to mechanize some aspects of his primary production, but still lacks access to financing.

He hires local labor to thresh his rice crop, and he reports that some of the rice is stolen during threshing. Still, he is unsure that mechanical threshing can deliver a competitive threshing price.

3 VALUE CHAIN ANALYSIS

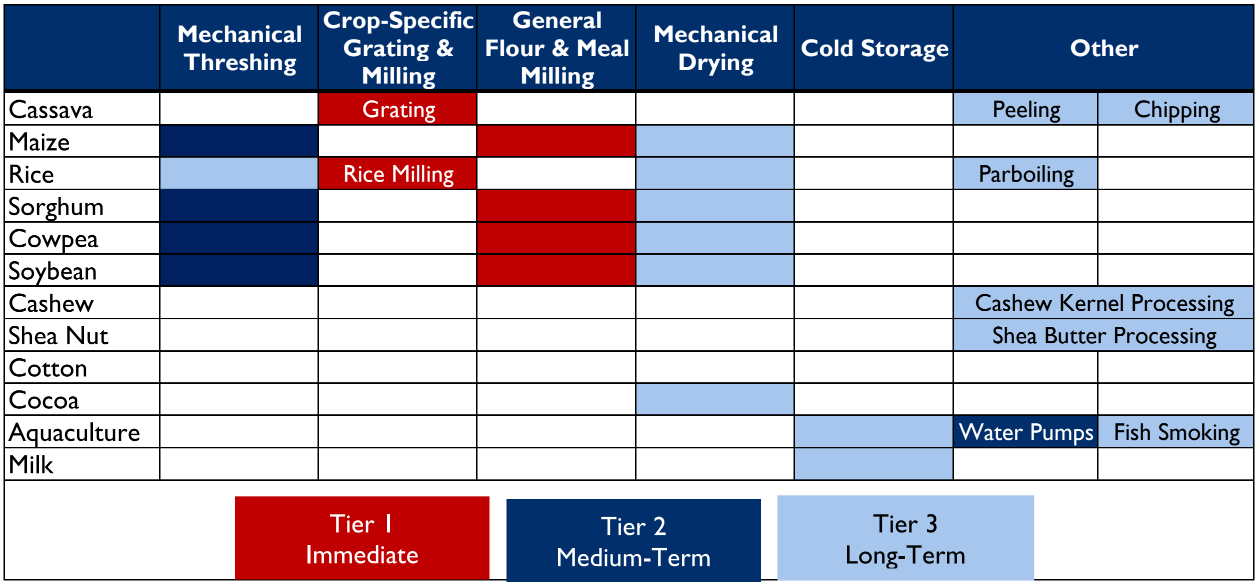
This study applies a productive use lens to post-harvest activities for 12 target value chains, focusing on opportunities for mini-grid electricity to improve the efficiency of the processing steps between the farm gate and locally marketed products. There are immediate opportunities to electrify currently fossil-fueled and manually performed processing activities for several of the key crops in rural Nigerian communities. This section summarizes these findings, and **Appendix A** provides in-depth analysis on every crop and value chain activity mentioned here.

3.1 SUMMARY OF ANALYSIS FINDINGS

As explained in **Section 2.3**, this study uses four criteria—Local Capacity, Offtake Market, Electric Equipment, and Scalability—to sort productive use opportunities into three tiers based on the support required to electrify them. **Figure 7** shows the ranking for each activity associated with each crop, while **Table 3** shows deployment-readiness across each criteria contributing to this ranking.

There are three clear Tier 1 activities across six crops primed for immediate electrification and implementation in Nigeria. Cassava grating, rice milling, and flour milling (across several grains) all have strong fundamental characteristics indicating that electrifying them can be straightforward and successful. Each of these opportunities requires little to no market development support in order to be implemented today and at large scale. For flour milling, this potential is further strengthened by the opportunity to use multi-crop milling equipment to broaden the local processor's business opportunity and reduce market risk (see **Appendix A.1** for the potential of multi-crop mills and threshers). **Section 4** explores whether these opportunities are commercially viable for processors and beneficial to mini-grid economics.

Figure 7: Summary of Tier Rankings Based On In-Depth Analyses of Crop and Value Chain Activity Combinations



	Mechanical Threshing	Crop-Specific Grating & Milling	General Flour & Meal Milling	Mechanical Drying	Cold Storage	Other	
Cassava		🟥 Grating				▨ Peeling	▨ Chipping
Maize	🟦		🟥	▨			
Rice	▨	🟥 Rice Milling		▨		▨ Parboiling	
Sorghum	🟦		🟥	▨			
Cowpea	🟦		🟥	▨			
Soybean	🟦		🟥	▨			
Cashew						▨ Cashew Kernel Processing	
Shea Nut						▨ Shea Butter Processing	
Cotton							
Cocoa				▨			
Aquaculture					▨	🟦 Water Pumps	▨ Fish Smoking
Milk					▨		

🟥 Tier 1 Immediate

🟦 Tier 2 Medium-Term

▨ Tier 3 Long-Term

Tier 2 crops have definite medium-term potential if provided with support to overcome one or more barriers to deployment, particularly regarding the capacity of local actors and economies to adjust to mechanization. Value chain actors may need to change behavior to adapt to the requirements of mechanized processing. For example, adoption of a centralized multi-crop thresher depends on farmers' ability and willingness to transport their dried cereals to the town center, rather than hiring labor to thresh grains in the field. These adaptations are feasible but may require additional effort.

Tier 3 activities have longer-term potential if extensive barriers are addressed. For example, cassava chipping is simple to mechanize, but mini-grid-suitable communities are not connected to the industrial markets where the chips are sold (**Appendix A.2.3**). The viability of cassava chipping as a productive use activity thus depends upon the ability of other actors to support access to an industrial offtake market where orders are demarcated in thousands of tons per year. Today, ensuring this access would require coordination of disparate cassava growers and chippers, aggregation and quality control, and purchase agreements with large corporations. For other activities, electric appliances do not exist, and may be challenging to develop. For example, electric parboilers could conceivably be built but would probably be cost-prohibitive to operate under a mini-grid tariff (Box A.4 in **Appendix A.4.3**). Others need a rare combination of enabling conditions: milk chilling operations require collocation of dairy-producing communities and industrial dairy processors (**Appendix A.7**).

Table 3: Value Chain Activities Analyzed, Including Tier Ranks and Scoring Summaries

SUPPORT REQUIRED: **● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant**

	Activity	Value Chain	Local Capacity	Offtake Market	Electric Equipment	Scalability
TIER 1	Grating	Cassava	●	●	●	●
	Flour Milling	Maize	●	●	●	●
		Sorghum	◕	◕	●	◕
		Cowpea	●	●	●	●
		Soybean	◕	◕	●	◕
	Rice Milling	Rice	●	●	●	●
TIER 2	Threshing	Maize	◑	●	◕	●
		Sorghum	◑	◕	◕	◑
		Cowpea	◑	●	◕	◕
		Soybean	◑	◕	◑	◑
	Water Pumping	Aquaculture	◑	●	◕	◔
TIER 3	Threshing	Rice	◔	●	◑	●
	Parboiling	Rice	◑	●	◔	●
	Shea Butter	Shea Nuts	◑	◔	◑	◔
	Drying	Maize	◔	◑	◔	◕
		Sorghum	◔	◑	◔	◔
		Cowpea	◔	◑	◔	◕
		Soybean	◔	◑	◔	◑
		Rice	◔	◑	◔	◕
		Cocoa	◔	◑	◑	◔
	Cold Storage	Aquaculture	◑	◔	●	◔
		Milk (chilling)	◔	◑	◕	◔
	Peeling	Cassava	◑	◕	◔	◑
	Chipping	Cassava	◕	◔	◕	◔
	Fish Smoking	Aquaculture	◑	◕	◔	◕
	Kernel Production	Cashew	◔	◔	◑	◑

3.1.1 Key Considerations for Evaluating Productive Use Opportunities

Sifting through the range of crops and activities considered in this study yields several core principles to guide consideration of other productive use opportunities. In addition to the prioritization criteria used to rank activities, applying these considerations can help avoid fixating efforts on crops or activities that are not well-suited to electrification.

Volume is the key to profitability in mechanized agricultural processing: When investing in new equipment, operators must be confident they can pay back the upfront cost with fee-for-service charges or value-add margins from the commodities they process. The presence of manual alternatives limits the ability for operators to increase fee-for-service charges, and most smaller processors do not have much control over the selling price of their product. Operating costs are driven by fuel or energy expenses, which the operator also does not control. The key constraint on operators' ability to pay off a capital investment is almost entirely the number of kilograms, tons, or bags of crops they can process over time (e.g., **Figure 53**). Equipment operators must be sure they can source enough raw material or attract enough fee-for-service customers to achieve a break-even level of capacity utilization. This reality favors crops already grown and processed in large quantities, as well as multi-crop equipment that can process communities' diverse harvests.

Minimize risk by selecting activities that are already mechanized and consult value chain experts: Agricultural development literature is full of examples of well-meaning projects that failed because of the complexity and risk inherent in agricultural processing. The surest measure of market demand for mechanization is its current prevalence in the target community. Energy actors who are considering productive use programs to stimulate latent activities must do so with a full understanding of the risks, preferably in partnership with agriculture experts.

Use electricity for what it does best: Electricity has a comparative advantage over fossil fuels and firewood when its highly ordered potential is used to efficiently drive motors and pumps. Heating is the least favorable use of electricity compared to alternatives that burn, especially at cost-reflective mini-grid tariffs.

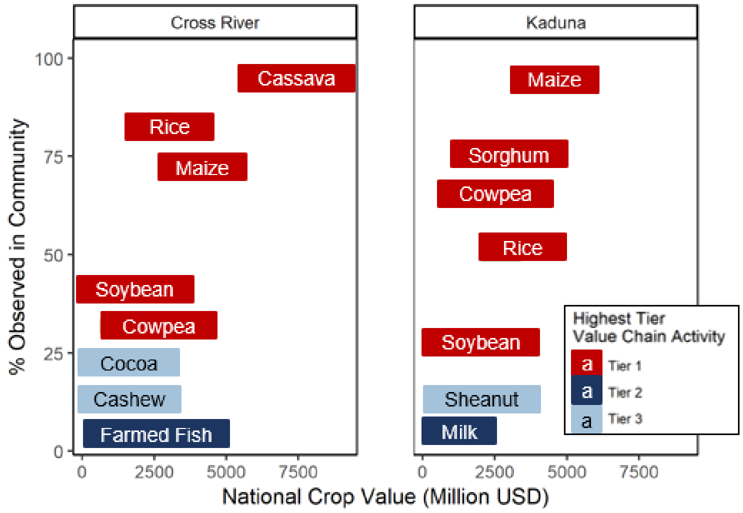
Equipment specifications matter: Working with food products means accommodating customers' deeply held preferences for quality, texture, taste, and color. In addition, mini-grid power systems and meters pose technical constraints on equipment design (e.g., phase, voltage, in-rush current). Only thorough pilot tests can ensure the selected equipment balances customer preferences with these operating limitations.[5]

3.1.2 Supporting Value Chain Analysis Survey Data

Survey data collected in this study confirm that cassava, rice, maize, cowpea and sorghum are locally and nationally eminent, supporting their prioritization. Considering their representation in field data and national production statistics, as shown in **Figure 9**, maize and rice emerge as the most frequently cultivated crops in the two target states. Cassava is especially important in Cross River's sub-humid agroecological zone. In Kaduna's semi-arid zone, drought-resistant crops like cowpea and sorghum were grown alongside maize and rice.

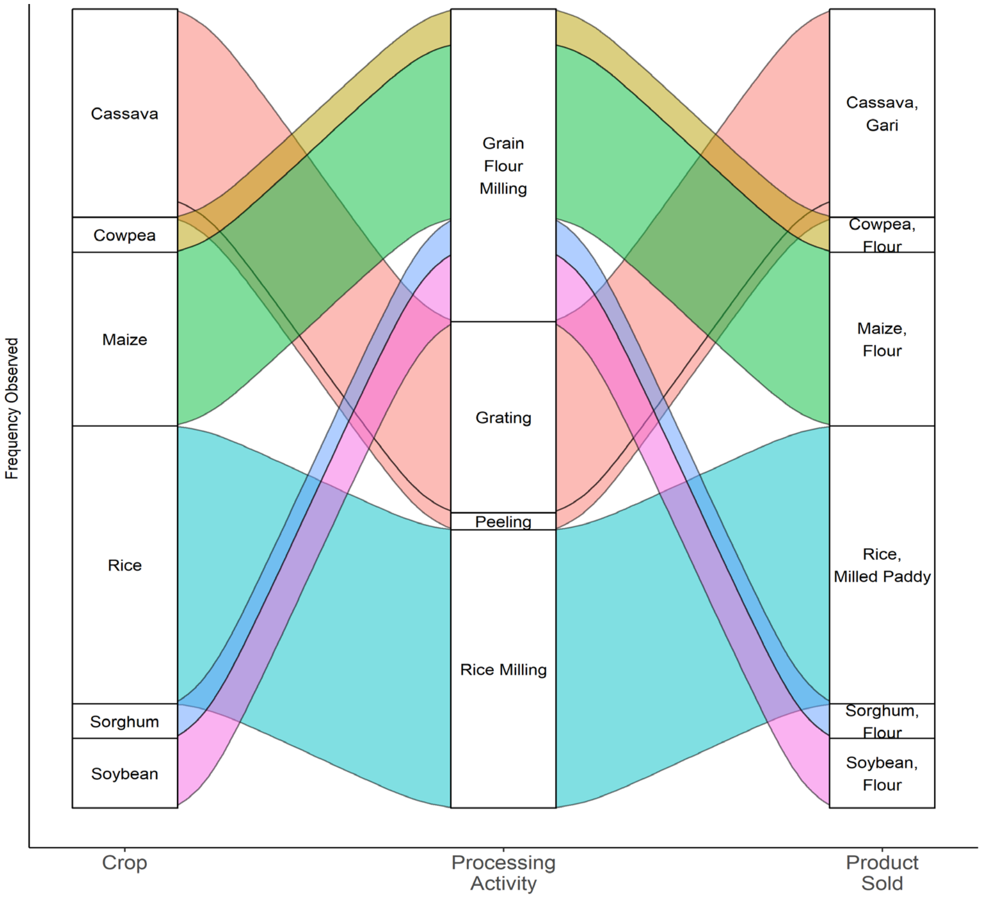
Survey data also confirms that rice milling, cassava grating, and grain flour milling are the most prevalently mechanized activities observed in the mini-grid-suitable communities visited. **Figure 8** shows the value chain flows for 52 agricultural processors who have mechanized at least one processing activity in their business. On the ground, mechanized processing activities are dominated by the crops that are most prevalently farmed at large volumes in the target geographies. Cassava is grated and then processed into *gari*; maize, sorghum, soybean and cowpea are milled into flour; and paddy rice is milled to remove the husk and bran before parboiling. Other processing activities are also observed but were not reported to be mechanized (e.g., drying and parboiling).

Figure 9: Summary of Crop Production at Local and National Scales



Community observation rates show the percentage of communities surveyed that reported five or more growers of a given crop. National crop value refers to the value at the farm gate, reported as the 2012–2016 average in constant '04-'06 US dollars.[5]

Figure 8: Value Chain Flows for Agricultural Processors Who Use Mechanization For At Least One Processing Step in Their Business

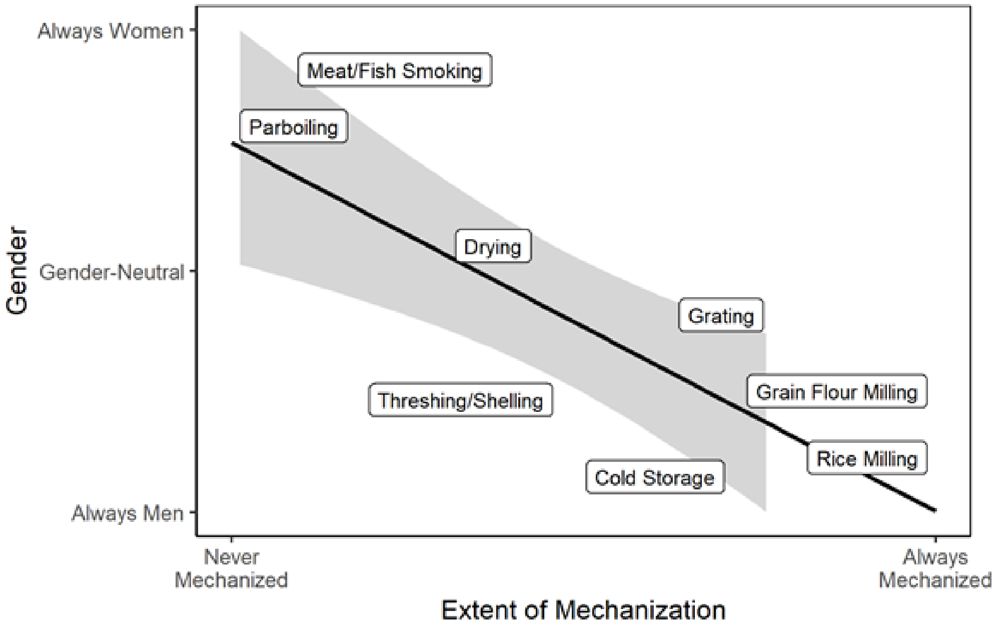


Value chain activities that are not mechanized are excluded. The size of each flow represents the frequency of its observation in our dataset.

3.1.3 Gender Considerations Across Activities

Today, men are the *de facto* operators of mechanized value chain activities. Mechanization of previously manual operations through electrification programs may exacerbate gender income imbalances if not countered with deliberate consideration of gender in program design. **Figure 10** shows the extent of mechanization and gender representation across the processing activities recorded in field surveys. Across the target states, rice milling, cassava grating, and grain flour milling emerge as the most prevalently mechanized. While this data is based on a limited sample size of 133 respondents, it shows a clear relationship between the extent of mechanization and gender representation: the more mechanized the operation, the lower female participation tends to be. Activities associated with cooking-like work—such as fish smoking and parboiling of rice—tend to be conducted by women. Gender representation does appear to vary slightly across states with varying cultural norms and practices, but definitive conclusions about these patterns with the data available cannot be made, and further study is required.

Figure 10: Trends in Mechanization and Gender Representation in Value-Add Activities Included in Field Surveys as Reported by Local Processors and Community Champions



Error Bounds Denote the 90% Confidence Level Interval for the Trendline.

3.2 VALUE CHAIN-SPECIFIC FINDINGS

Appendix A provides detailed findings across all crops evaluated. The following is a summary of findings for each individual value chain included in the study.

Cassava is a critical staple that is nearly always mechanically processed before consumption or sale. Electrification of cassava graters by replacing aging diesel listers with electric motors will decrease operations and maintenance costs significantly (Tier 1, **Appendix A.2.3**).

Maize was the most widely cultivated crop across the two target states and many small milling businesses grind maize into flours and meals using fossil-powered motors. Maize flour milling is a Tier 1 opportunity with large potential to scale across Nigerian mini-grids, while maize threshing is a Tier 2 opportunity that shows promise if the business model for a stationary mini-grid-connected thresher can be proven (**Appendix A.3.3**).

Rice is processed by small-scale processors 80% of the time, most of whom operate outdated, one-stage, diesel rice mills. Introducing modern electric two-stage mills is a Tier 1 opportunity that can improve head rice yields and produce a higher quality product fetching a 50% price premium (**Appendix A.4.3**). Rice is growing in popularity with farmers and consumers and is further supported by the Federal Government's measures to limit imports.

Aquaculture is one of the least prevalent value chains studied, but also one of the fastest growing, averaging 12% annual growth for the past three decades. An unknown fraction of fish farmers use ground-source or aeration water pumps for their ponds. If pumping loads are located within mini-grid service territory, mini-grid-powered pumps can beat diesel pump operating costs by 25% (Tier 2, **Box A.5 in Appendix A.5.3**). Customer preferences limit demand for cold storage of catfish—the predominant aquaculture species—in the near term (Tier 3, **Appendix A.5.3**).

Cocoa beans are an important export crop but most value add comes from commercial processing outside of mini-grid-suitable communities (**Box A.6** in **Appendix A.6.3**). Rural actors' earnings are mostly from the sale of primary production in the form of dried beans, and top priorities for development of the cocoa industry are improvement of smallholder yields and market bargaining power, which are not energy-related challenges (Tier 3, **Appendix A.6.1**).

Milk is the most perishable commodity studied, requiring cooling within hours of collection to prevent spoilage. If milk chilling operations were found to occur in prospective mini-grid communities, the loads would almost certainly be cost-effectively served by mini-grids (Tier 3, **Appendix A.7.3**). However, a very specific set of criteria must be satisfied for a milk collection facility to be built today, including interest from a commercial dairy offtaker, a capacity building program for the local community, and a mini-grid site located within the offtaker's catchment area.

Cashew kernels are a luxury good that demand high quality for a premium price in formal markets. Mechanized cashew processing effectively requires a rural factory operating a suite of processing equipment with the expertise to meet stringent quality standards. (Tier 3, **Appendix A.8.3**).

Cowpeas are hardy, nutritious legumes that are commonly grown, processed and consumed within mini-grid-suitable communities. Properly operated, multi-crop mills can be utilized to process cowpea into flours, pastes and meals alongside other cereal grains (Tier 1, **Appendix A.9.3**). Cowpeas are second only to maize in prevalence of mechanical threshing today (Tier 2, **Appendix A.1.1**).

Soybean is the industrially oriented cousin of cowpea in Nigeria. Compared to cowpea, it is less of a local staple food and less geographically common, but opportunities to mechanize soybean processing strongly resemble those for cowpea in soybean-producing communities including both Tier 1 and Tier 2 (**Appendix A.10.3**).

Sorghum grows even on marginal lands with limited water resources, making it an important food security crop, especially in northern communities (**Appendix A.11.1**). Compared to maize, sorghum is much more likely to be self-consumed by farmers rather than marketed as a cash crop. If sorghum can be milled (Tier 1) or threshed (Tier 2) alongside other grains, it may improve capacity utilization of multi-crop equipment utilized for other grains cultivated in larger quantities (**Appendix A.1.2**).

Cotton is a common cash crop, but local farmers do not engage in value-add cotton processing. At farm level, major constraints to sector growth are in primary production and in cotton contamination during harvesting (**Appendix A.12.1**). Neither of these limitations are directly addressable with electricity.

Shea Nuts are collected from naturally occurring trees and are typically consumed locally, without reaching domestic or international markets. Local processors produce shea butter in small batches using traditional methods. While some butter production steps could be mechanized, significant efforts would be required to source high volumes of nuts from disparate producers, build quality control capacity, and connect to higher-value markets (Tier 3, **Appendix A.13**).

4 ECONOMIC VIABILITY OF ELECTRIFYING PROCESSING ACTIVITIES

Beyond the prevalence of productive use activity and availability of electric equipment, a critical question remains: is it economically viable to electrify these productive use activities with mini-grid power? To answer this question, this study assesses the economic viability of investing in and switching to electric equipment for each of the Tier 1 activities identified (see **Section 3.1**) under prevalent processor business approaches— either buying raw material and selling the processed product (BnS), or a fee-for-service (FFS) modality in which they process material for others. A total of five combinations of crops, activities, and processor modalities are included (**Table 4**). Finally, a streamlined mini-grid economic analysis to explore the tariff impacts from adding these productive use loads is shown.

Table 4: Summary of Combinations of Crops, Activities and Processor Modalities Analyzed

Crop	Activity	Processor Modality
Cassava	Grating	Buy raw material and sell processed product (BnS)
Cassava	Grating	Fee-for-service (FFS)
Maize	Flour Milling	FFS
Rice	Milling	BnS
Rice	Milling	FFS

4.1 PROCESSOR CASH FLOW ANALYSIS

Analysis finds that there is a positive and compelling economic case for each activity analyzed, and with reasonable assumptions all cases can demonstrate positive net present value (NPV). For these priority value chains and activities, electric processing equipment powered by a mini-grid enables processors to save on operating costs and can even increase revenue compared with existing fossil-powered equipment. This analysis is based on cash flow modeling with inputs from the study's survey results in Kaduna and Cross River states, literature review, and expert interviews (as explained in **Section 2**). The methodology for this analysis, including specific assumptions and detailed results, is shown in **Appendix C.**

While results are consistently positive**, the degree of economic viability is most contingent on the volume of crops processed**. In order to reach a "breakeven" threshold of $0 NPV, cassava-based activities require approximately 670–720 tons per year, rice-based activities need 70–160 tons per year depending on the sale modality used, and maize-based activities require 60 tons per year.

Compared with what is necessary to reach these minimum levels of economic viability, surveys and research show much higher levels of production in mini-grid-suitable communities today. Survey results show annual processing volumes of approximately 270–1,460 tons of cassava, 360–3,120 tons of rice, and 30–220 tons of maize, while research show that typical communities annually produce over 28,000 tons of cassava, 1,300–6,000 tons of rice (varying by region),

A basin of manually threshed soybeans awaiting cleaning and milling into whole flour in Anguwan Malam Dogo community, Kaduna state.

and 1,100 tons of maize. At the community level, this indicates that there is more than enough production today to support multiple processors, even if less than 100% of the production is ultimately processed in the community. Furthermore, it is reasonable to assume that over time these production volumes may increase as access to reliable electricity spurs local economic development.

Table 5: Summary of Business Case Cash Flow Analyses

	Cassava Grating (*Gari*)		**Grain Flour Milling**	**Rice Milling**	
Assumptions:	1,000 kg/hour capacity 2,500 kg/day processed $3,940 capital cost 5 kW motor		300 kg/hour capacity 300 kg/day processed $830 capital cost 3 kW motor	1,000 kg/hour capacity 1,000 kg/day processed $1,800 capital cost 11.2 kW motor	
	BnS	**FFS**	**FFS**	**BnS**	**FFS**
NPV: Electric Equipment	$5,500	$2,900	$2,100	$8,800	-$600
IRR	73%	53%	108%	179%	19%
Discounted Payback (years)	2.0	3.2	1.3	0.7	n/a

At the processing volumes indicated in survey data, investment economics are consistently strong across all activities and sale modalities. As **Table 5** shows, all cases except fee-for-service rice milling have a positive NPV over the investment lifetime, ranging from roughly $2,100 to as high as $8,800, and discounted payback times between a little over 3 years to less than a year. There is a significant difference in NPV between the buy and sell and fee-for-service rice miller sale modalities because buy and sell millers cut out the middleman and capture a price markup by playing the trader role, and they also enjoy the benefit of increased milling efficiency from the electric equipment (increasing yield and revenue). These economics illustrate an important takeaway for fee-for-service processors, who will need to adapt their pricing structure to compete. For example, if fee-for-service rice millers increase their fee to reflect the better service they are providing with an electric mill, by 10%, or $1 per ton, the investment becomes economically viable.

Beyond processing volume, investment economics are sensitive to a number of other factors. Sensitivity analyses are conducted to test key variables, including sale price, electricity price, financing specifications, and others. This analysis shows that within reasonable increases or decreases of these variables, electrifying these activities remains economically viable. **Table 6** shows the value of sensitivity variables that will set NPV to zero, when other inputs are left unchanged. These results provide an indication of the "ceiling" or "floor" for the value of each assumption that will make the investment in electric equipment economically viable. For example, for a FFS rice miller to break even the electricity tariff would need to drop to about $0.5/kWh (compared to $0.6/kWh modeled) or the business owner would need to increase their fee to $13/ton (compared to $12/ton modeled).

Table 6: Value of Variables That Will Result In A Breakeven NPV Of Zero Over The Lifetime Of The Equipment

		Cassava Grating (*Gari*)		**Grain Flour Milling**	**Rice Milling**	
		BnS	**FFS**	**FFS**	**BnS**	**FFS**
Production volume (t/year)	Baseline	196	196	94	156	156
	Floor	670	718	55	68	170
		BnS	**FFS**	**FFS**	**BnS**	**FFS**
Capex ($)	Baseline	$1,100	$1,100	$830	$1,800	$1,800
	Ceiling	$6,000	$3,700	$2,700	$9,900	$1,200
Electricity price ($/kWh)	Baseline	$0.6/kWh	$0.6/kWh	$0.6/kWh	$0.6/kWh	$0.6/kWh
	Ceiling	$1.1/kWh	$0.9/kWh	$1.3/kWh	$1.8/kWh	$0.5/kWh
Sale price or FFS charge ($/t)	Baseline	$320/t	$11/t	$17/t	$68/t	$12/t
	Floor	$311/t	$10/t	$10/t	$68/t	$13/t
Debt interest rate (%)	Baseline	30%	30%	30%	30%	30%
	Ceiling	73%	53%	108%	179%	19%

4.2 IMPACT ON MINI-GRID ECONOMICS

A key aspect in considering the value of agricultural productive use electrification is its impact on mini-grid economics. If compatible with mini-grid design, load profiles, and generation profiles, serving these loads could improve the economics of a mini-grid and reduce the tariff required to support project returns. However, if the load is not compatible—for example if it is spiky, seasonal, and noncoincident with low-cost generation availability—then project economics could be harmed. While a full analysis of mini-grid technoeconomic impacts is outside the scope of this study, provided here is a limited test of the impact on mini-grid economics of electrifying Tier 1 activities. To do so, mini-grid economics under five scenarios were analyzed (see **Table 7)** using a combination of HOMER Pro software and custom spreadsheet models while building on the study's survey findings and economic viability analysis of electrifying processing activities. The methodology and assumptions used are included in **Appendix C.1.4.**

Table 7: Summary of Mini-Grid Scenarios Analyzed

Scenario	**Added Productive Use**	**Mini-grid System Design**
BASE	None	Optimized hybrid system with solar PV, lead acid battery, and diesel backup with 50% oversizing to reflect current practice.[viii]
BASE+Cassava	Cassava grating	Same as BASE scenario.
BASE+Maize	Maize flour milling	Same as BASE scenario.
BASE+Rice	Rice milling	Same as BASE scenario.
BASE+All	All three	Designed without oversizing to show an ideally sized system.

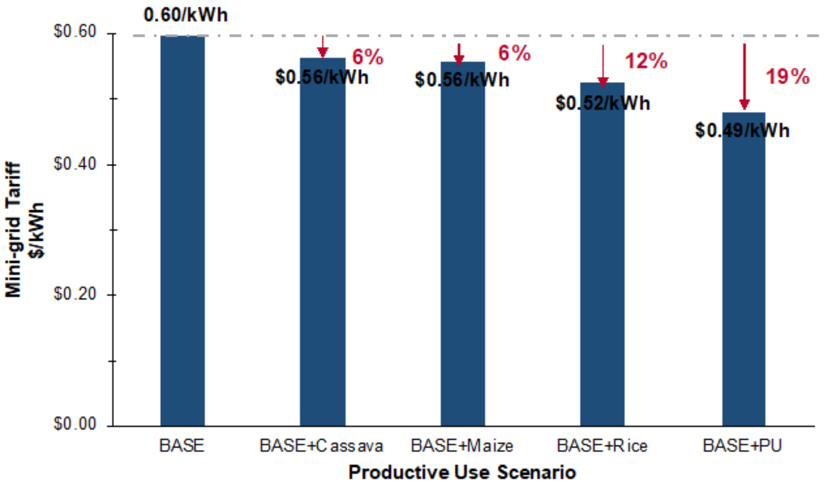
[viii] System oversizing is a common issue in mini-grid design and implementation, resulting in reduced capacity utilization and increased upfront cost. RMI analysis suggests a 30–50% oversized design is a reasonable assumption considering current demand forecast capabilities.

Simulation results find that expected loads from Tier 1 activities can improve mini-grid economics and enable lower cost-reflective tariffs for customers. **Figure 11** shows that, relative to a baseline scenario with a 77 kW PV-diesel hybrid mini-grid (without added productive use), mini-grid electricity tariffs in communities with electrified cassava grating, rice milling, and maize flour milling can be 6–19% lower while still earning a 15% internal rate of return (IRR) for mini-grid investors. Furthermore, if the community electrifies all three activities and the mini-grid design fully integrates them, a 26% reduction in tariff can be achieved. This assumes the number of processors found in a community of this size as reported in survey results, meaning nine cassava graters, five rice mills, or 12 flour mills are electrified, adding 30%, 15% and 12% load to the existing load in BASE scenario, respectively (see the 24-hour load profiles in **Figure 12**).[ix]

The additional productive use loads improve the mini-grid's economics by increasing the system utilization rate and increasing sales to generate more revenue. While the volume of additional electricity sales is helpful, the timing of the added load is critical. Cassava grating, for example, represents a greater increase in both peak demand and energy usage compared to rice milling, but the latter has a greater impact on reducing the mini-grid tariff (**Figure 12**). This is because rice milling operations occur primarily during the day (as reported by survey respondents), which better matches the availability of low-cost solar generation and avoids the need to run additional expensive diesel generation. Mini-grid operators can take advantage of this benefit by adding agricultural processing loads that already occur during the day, or by encouraging customers to change their behavior to shift loads during these hours (for example through time of use tariffs).

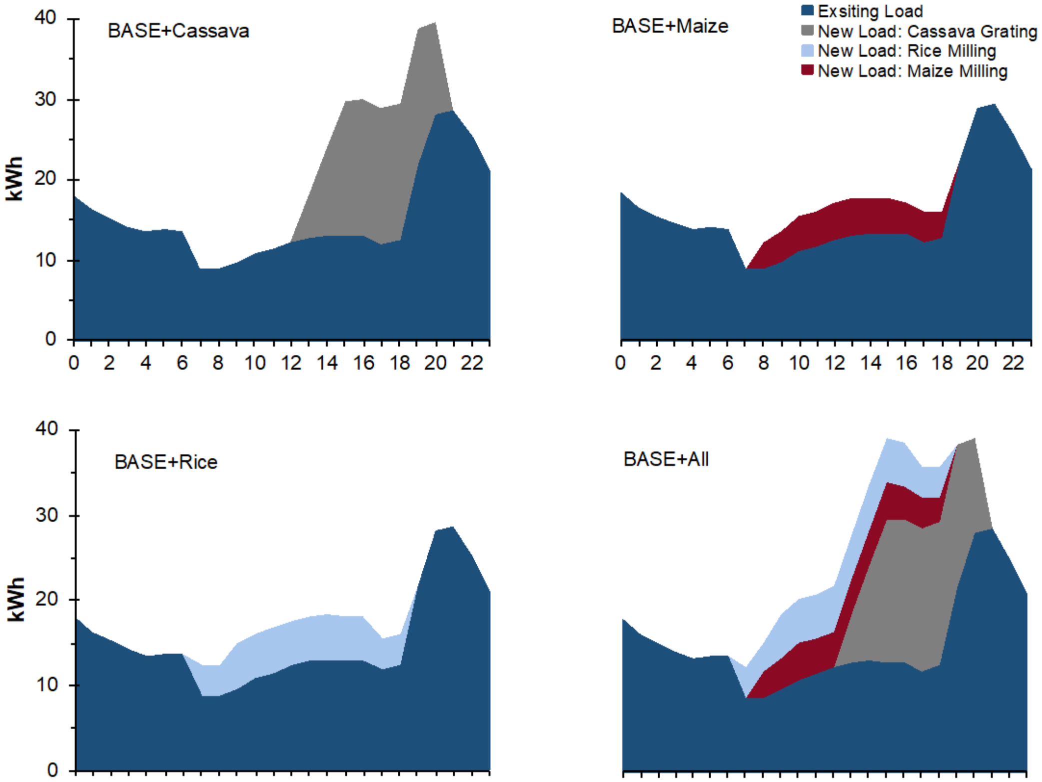
In the BASE+All scenario, an optimized mini-grid design calls for an additional 10 kW of PV capacity, equally sized genset, and 40 kWh more battery storage compared to the BASE scenario. There is significantly more daytime load in the BASE+All scenario (**Figure 12**), most of which can be served by solar generation in combination with battery storage. Despite higher upfront capital investment, mini-grid operating costs are lower and revenues increase from the additional load. Productive use has the potential to significantly reduce the tariff, making the mini-grid more financially viable.

Figure 11: Mini-Grid Tariff to Achieve 15% IRR For Investors Under Different Scenarios



[ix] Based on the breakeven volume analysis in **Appendix C**, estimated production in community of this size surveyed in Kaduna and Cross River can supply enough raw materials for these numbers of processors.

Figure 12 24-Hour Load Profiles Under Different Scenarios



While this analysis provides initial insight into the potential economic impacts of electrifying these particular productive uses in a rural mini-grid context, additional study is warranted. The limited scope of this study does not provide for a broader analysis of all potential agricultural productive uses and did not allow for specific site studies. In the analysis, these productive loads are consistent throughout the year as reported by surveyed processors. Other agricultural processing activities, however, can be highly seasonal and activity level might vary depending on harvest. For example, if rice millers are only active for eight months of the year, because of the similar cost of maintaining the mini-grid system while revenue is decreased, tariff reduction would only be 7% instead of 12% compared to the BASE scenario. If seasonal productive loads are to be served by mini-grid, the seasonality should be more carefully calibrated when optimizing the system design.

Mini-grid developers should test the assumptions used here within their own analyses, and further consideration of managing technical dynamics, such as inrush current, will be important. Given the number of motors required in the scenarios here, it is likely that the reference mini-grid would be capable of supporting inrush current under typical operations. But further analysis would be required to understand the real-time impact on a specific mini-grid system before implementation at scale.

5 BUSINESS MODEL OPTIONS

The economics of the opportunities presented in **Section 4** are clearly attractive, but commercial business models are needed to take advantage of them. As defined here, the term "business models" refer to the funding flows and relationships between actors to enable equipment purchases. These business models must address the major barriers limiting the implementation of electrified agricultural productive uses at scale in Nigeria. With this section, major barriers are identified, and two key business models that can address them to enable electrification of priority agricultural productive uses for the Tier 1 and Tier 2 activities considered are presented. An overview of the business models in this section and an in-depth description of each model is presented in **Appendix D.**

5.1 BARRIERS TO PRODUCTIVE USE

There are five primary barriers limiting the implementation of electrified agricultural productive uses at scale in Nigeria: access to credit for equipment purchase, availability of reliable electricity, awareness and education, access to markets, and access to equipment.

Barrier 1: Lack of access to credit for equipment purchase. Up-front capital costs often prevent customers from purchasing equipment, electric or otherwise. Most small-scale processors and mini-grid developers lack the credit history and collateral that banks require to provide financing with reasonable terms. Survey results support this, as all but one of the small-scale processors interviewed (53 out of 54 respondents) identified access to loans as the main barrier limiting their ability to grow their processing capacity. In fact, credit organizations in Nigeria are not active in the rural communities surveyed: none of the community champions interviewed identified microfinance institutions or commercial bank agents active in their communities. Survey results suggest that small holder farmers and processors that do access credit do so through farmer cooperatives.[x]

Barrier 2: Lack of availability of reliable electricity. Access to reliable electricity to operate equipment in rural communities is another barrier preventing customers from purchasing and using electric equipment. A would-be small-scale processor will not be willing to invest in electric equipment if she or he does not feel they will be able to sufficiently operate the equipment to recover their investment. The image to the right shows a queue of maize bags waiting to be processed in Waru, a peri-urban community in the outskirts of Abuja. Small-scale processors and their customers often must wait for days for power to return to the community to mill maize and take the flour to market.

In grid-served communities, fee-for-service processors prefer electric mills but must often pause milling for days at a time when the lights go out.

Survey results also support this finding as the majority of small-scale processors that identified more than one barrier limiting their ability to grow their processing capacity stated that access to reliable electricity to operate machines is the second most important barrier they face.[xi] Survey results also suggest that

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[x] None of the community champions interviewed identified active MFIs and commercial bank agents in their communities. 16 out of 20 community champions state that the majority of active cooperatives offer financing services.

[xi] 19 of 24 processors that included a second barrier (beyond access to credit) included access to electricity as the second most important barrier limiting their ability to grow their processing capacity.

access to reliable power is important to the wider community. Most respondents included access to reliable power as the most important issue that would improve their communities.[xii]

Barrier 3: Lack of awareness and education for would-be equipment purchasers and equipment and electricity providers. The un- and underserved populations of Nigeria are large and dispersed across the country—it will be critical to ensure that they have the knowledge and skills to take advantage of opportunities to invest in electric equipment for productive use. Electrified agricultural productive use cannot scale unless would-be equipment purchasers are aware of the opportunities available to finance and purchase electric options and have the skills and desire to pursue them. Survey results suggest that it is challenging to access extension or business development services in agricultural communities, as 93 out of 113 respondents said it was difficult or very difficult to do so.

Barrier 4: Lack of access to market. The potential for agricultural productive use is greatest if guided by demand for products. To raise financing for equipment purchases at reasonable rates will depend on convincing financial institutions that revenue streams are low risk, meaning that there must be a strong market for the relevant product. As such, new entrants to Tier 1 activities or actors developing Tier 2 activities will need to confirm the existence of a market to sell their products and services. Nonetheless, only four out of the 54 processors interviewed stated lack of market access as one of the most important barriers limiting their ability to grow their processing capacity, and the analysis of Tier 1 activities against market criteria (see **Section 3 and Appendix A**) suggest that financial institutions may perceive this as a higher risk than small-scale processors do.

Barrier 5: Lack of access to equipment. For electricity systems to serve agricultural productive use, drive economic development, and achieve financial viability, their customers must have access to electric equipment. This may seem obvious, but experience to date with the development of mini-grid systems in Nigeria has not always shown this to be a primary consideration in project development, and potentially only considered after operations begin. While a full assessment of appliance availability is outside the scope of this study, a preliminary review of the appliance market in Nigeria suggests that existing vendors can provide or manufacture electric equipment for the Tier 1 and Tier 2 activities identified here (see **Appendix A** and **Appendix B**). Additional research is needed to test these locally available electric equipment options to ensure compatibility with mini-grid systems, user requirements for efficiency, and end-consumer product preferences.

5.2 PRIORITY BUSINESS MODELS FOR TIER 1 AND TIER 2 ACTIVITIES

There are two key business models—the **Facilitator Model** and **Processing Center Model**—that can be used to develop Tier 1 and Tier 2 activities. These business models build on the experience to date of mini-grid developers who have tested approaches to supporting productive uses of electricity in Nigeria and elsewhere. Both models described here consider the needs of various actors to introduce alternative arrangements and roles, where appropriate, to improve performance and scalability. This study also specifies when each business model makes sense within the Nigerian context to help funders remain flexible and tailor the design of interventions to conditions they face. This section provides an overview of the models, while **Appendix D** describes each model in further detail, defining the roles and responsibilities and providing a deeper assessment of each model's performance against the barriers noted above.

The **Facilitator Model** is led by a facilitator who enables small-scale processors to invest in equipment by serving as their education resource and connection point to finance providers. While the small-scale processor is ultimately responsible for the credit and operational risk, the facilitator builds awareness about the investment opportunity and provides business development training to support loan applications

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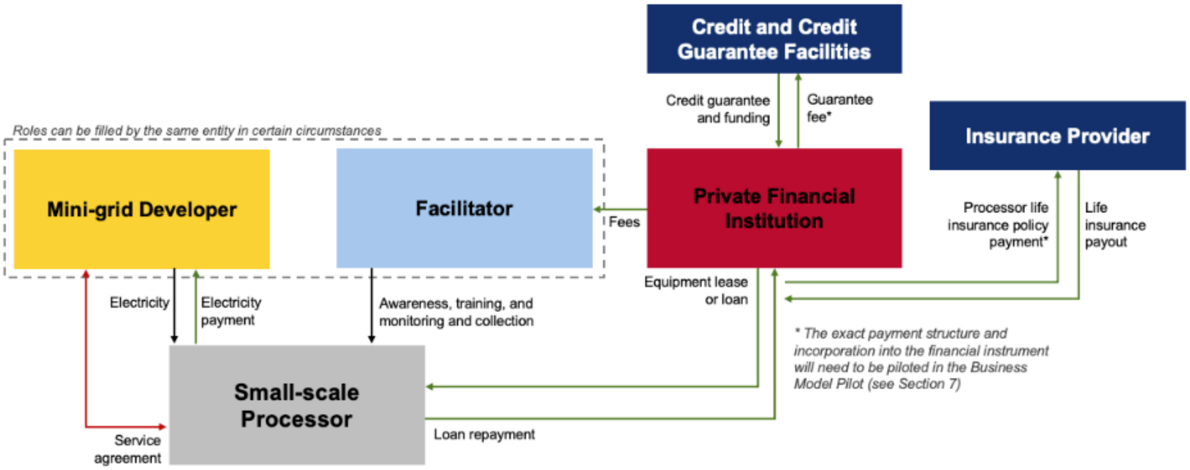
[xii] 75 respondents included access to reliable power as the most important issue that would improve their community, followed by access to education for their children as the second most frequently mentioned issue considered (63 respondents) most important by respondents.

and equipment selection, as shown in **Figure 13**. Over time, once the viability of lending to small-scale processors is proven, the role of the facilitator would be phased out or reduced and the private financial institution (PFI) assumes the role of identifying and selecting would-be processors. One key benefit of the Facilitator Model is that it de-risks participation by third parties to provide financing and capacity building, which enables equipment purchases and reduces the burden on the mini-grid developer.

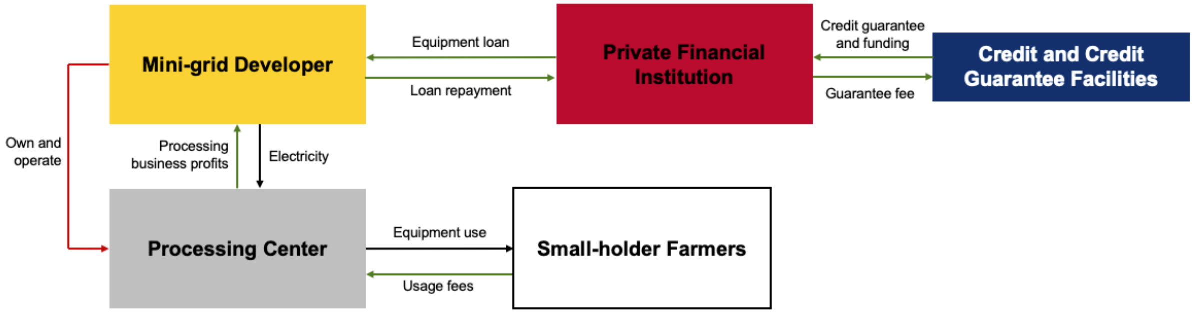
Figure 13: Institutional Arrangements of the Facilitator Model



The following are examples of actors well-suited to fulfill **key roles** in the Facilitator Model:

- A **small-scale processor** invests in electric equipment and is responsible for operating the equipment and repaying the equipment loan. They are a local entrepreneur that already invests in processing for sale in local markets and first-time buyers of electric equipment. **Appendix D.1.1** includes a profile of a small-scale processor.
- The **facilitator** leverages its local presence and relationships to connect small-scale processors to finance and equipment access. For an organization to fill the facilitator role, it must be embedded in the farming communities and have an operational model that aligns with the activities required by this role. For example, an organization like Solar Sisters, which specializes in selling and distributing solar equipment in un- or under-served communities, has an operational model aligned with the facilitator role as they already perform similar functions.
- A **private finance institution** (PFI) on-lends from the credit facility to the small-scale processor. The PFI should have experience lending to the agriculture sector and have a mandate to support financial inclusion. For example, LAPO Microfinance Bank meets both criteria.
- The **mini-grid developer** serves a limited role under the Facilitator Model, focusing on its core utility business of producing and selling electricity. As such, candidates suitable for participating in this model are those that have limited additional management capacity to assign to manage a new business line or would prefer to not diversify their business. In sector interviews mini-grid developers, both early entrants and experienced companies, often stated that they prefer a business model where they do not need to absorb additional operational responsibility and investment functions beyond their main business line.

Figure 14: Institutional Arrangements of the Processing Center Model



In contrast, the **Processing Center Model shown in Figure 14** relies on a mini-grid developer based in a rural community to invest in, own, and operate the equipment for a new processing service that existing entrepreneurs are not able to provide (**Section 5.2**).[xiii] Under the Processing Center Model, the mini-grid developer is ultimately responsible for the credit and operational risk. The Processing Center Model is appropriate for activities where there is proven demand for the product, but the activity is not prevalent in the local community. Using these criteria to determine when the Processing Center Model is appropriate can ensure that local entrepreneurs are not displaced by the mini-grid developer.

The following are examples of actors well-suited to fulfill **key roles** in the Processing Center Model:

- The **mini-grid developer** serves the most important role under the Processing Center Model, because in addition to providing reliable electricity service, it also owns the processing center, invests in the electric equipment, and is responsible for operating the equipment and repaying the equipment loan. Mature companies with experience deploying appliance financing programs, and a management structure that can accommodate additional business lines, are better suited to implement the Processing Center Model.
- A **private finance institution** on-lends funding from the credit facility to the mini-grid developer. Like in the Facilitator Model, the PFI should have experience lending to the agriculture sector because it will have a better understanding of common risks, already have mechanisms to address these risks, and be more willing to lend for agricultural activities. Alternatively, banks that are already lending to mini-grid companies may be more comfortable extending credit for a new credit line. The following banks are lending or have demonstrated interest in lending to mini-grid developers in Nigeria: Sterling Bank, First City Monument Bank, Access Bank, WEMA Bank Debt.[xiv]

A third model, the **Offtaker-Based Model**, is included in **Appendix D.** This model involves an offtaker investing in processing in rural communities and buying crops from surrounding communities. The Offtaker-Based Model is appropriate for activities that require significant volume to market effectively, and so require an actor that can coordinate across large catchment areas to achieve that volume. This model is relatively complex and less appropriate for Tier 1 and Tier 2 activities, a conclusion shared by the Nigerian policymakers, offtakers, and mini-grid developers consulted over the course of this study. However, the Offtaker-Based Model has long-term potential for several Tier 3 activities and warrants future consideration— an overview of the model is included in **Appendix D**.

[xiii] Similar approaches to the Processing Center Model have been proposed and tested before. For example, in the KeyMaker Model, the mini-grid company develops a second business line, using mini-grid electricity to produce and sell a product regionally or nationally. For more information see **Appendix D.2**.

[xiv] Nigeria Power Sector Program, "NEP Shortlisted Financiers Database," 2019

A petrol maize thresher operating in a peri-urban zone outside Abuja.

Both the Facilitator and Processing Center models address most barriers discussed in **Section 5.1**. The Processing Center Model requires fewer stakeholders than the Facilitator Model, but the Facilitator Model imposes a smaller burden on the mini-grid developer (see **Appendix D** for additional comparison against barriers). There are applications for both models, and deployment should be determined based on the particular situation in a given community. Considering this, the following applications are recommended:

- **Use the Facilitator Model for Tier 1 activities** because it will not displace local small-scale processors already engaged in these activities and is simple to implement. For activities that are prevalent today, the Facilitator Model ensures the local community captures the most value and does not impose an operational burden and credit risk on the mini-grid developer. The model has a relatively simple design and still addresses the key barrier that would-be processors face—access to credit. Furthermore, survey results and the analysis of local trade volumes suggest that demand for Tier 1 activities is strong enough in these communities to support implementation without a dedicated offtaker in the design.
- **Use the Processing Center Model for Tier 2 activities** because it would reduce the size of investment needed and would not displace local entrepreneurs. In general, mechanized Tier 2 activities are not as prevalent in rural agricultural communities because the investment size needed to develop a processing business is a barrier to entry for local small-scale processors. Processes that conserve the purity and integrity of the crop and where investment is a barrier to entry for small-scale processors are good candidates for this model. For example, threshing that can be consolidated in the town center and multi-purpose drying meet these criteria. The Processing Center Model is suitable for these conditions because the mini-grid developer would face lower investment costs by leveraging their existing operational capabilities.

The various crop and processing activity combinations examined in **Section 3** present different barriers to implementation, which will ultimately require different business models. A single business model need not apply to all situations and crop-activity combinations. Instead, understanding when each option is most appropriate will ensure success for both the agricultural community and mini-grid operator, and allow implementers to further adapt based on the conditions and needs they face in specific communities. Additional information and discussion of these business models is included in **Appendix D.**

6 DEPLOYMENT STRATEGY AND FINANCIAL IMPLICATIONS

For each of the business models described in **Section 5**, access to commercial finance is critical. The major barrier that small-scale processors face in purchasing electric equipment is the inability to access credit at reasonable terms. This section summarizes a recommended deployment strategy to fund equipment purchases by answering the following questions:

- What financing characteristics will enable small-scale processors to purchase electric equipment?
- How can PFI investment be de-risked to unlock and increase commercial financing?
- What is the flow of funding needed between institutions to disburse financing?

In answering these questions, this section focuses on the implications for Tier 1 activities, which represent quick-wins that are feasible to implement and can achieve stronger impact in the short to medium-term. Given this, the Facilitator Model is used for context, as it is most appropriate for immediate implementation with Tier 1 activities. However, the institutional arrangements—the roles of, and relationships between, actors—for disbursing funds under the Facilitator Model could similarly be used under the Processing Center Model.

This section first summarizes the financial instruments needed to unlock commercial financing and fund electric equipment purchases. A detailed description of these financial instruments is included in **Appendix E.** The study then estimates the size of investment needed nationally to fund equipment purchases for Tier 1 activities. A description of the methodology and assumptions used to estimate the funding required is included in **Appendices E.2** and **E.3.** Finally, institutional arrangements needed to disburse financing are defined.

Notably, the estimates for investment size are preliminary and the institutions identified are merely illustrative—none of the actors noted have committed to participating in the deployment strategy. Additional analysis by funders will be needed to define exact funding requirements and stakeholder engagement to identify participants interested in fulfilling roles specified in the deployment strategy.

6.1 UNLOCKING COMMERCIAL FINANCE AND FUNDING EQUIPMENT PURCHASES

Figure 17 shows the internal rates of return and expected paybacks of the equipment purchases for Tier 1 activities. The expected return on investment for most electric equipment purchases considered are large enough for small-scale processors to afford a cost of capital of around 30 percent.[xv] One notable exception is rice millers operating under a fee-for-service sales modality (FFS rice millers). FFS rice millers would be unable to afford a 30 percent cost of capital without increasing their fees. Different financial instruments should be considered for situations where the small-scale processor is profitable enough to cover higher rates of commercial sources of funding, and for those where the processor cannot immediately be profitable at commercial rates.

[xv] Interview with a Nigerian commercial bank in November 2019. The commercial cost of capital as an input to estimate the size of funding required is conservatively assumed, though lower rates may be available from other financiers, particularly development financing institutions. For example, Bank of Industry's Government Enterprise and Empowerment Programme (GEEP) charges 10 to 15 percent interest for loans to mini-grid developers, and up to 5 percent to micro-processors.

Figure 15: Summary of Financial Results of Tier 1 Activities

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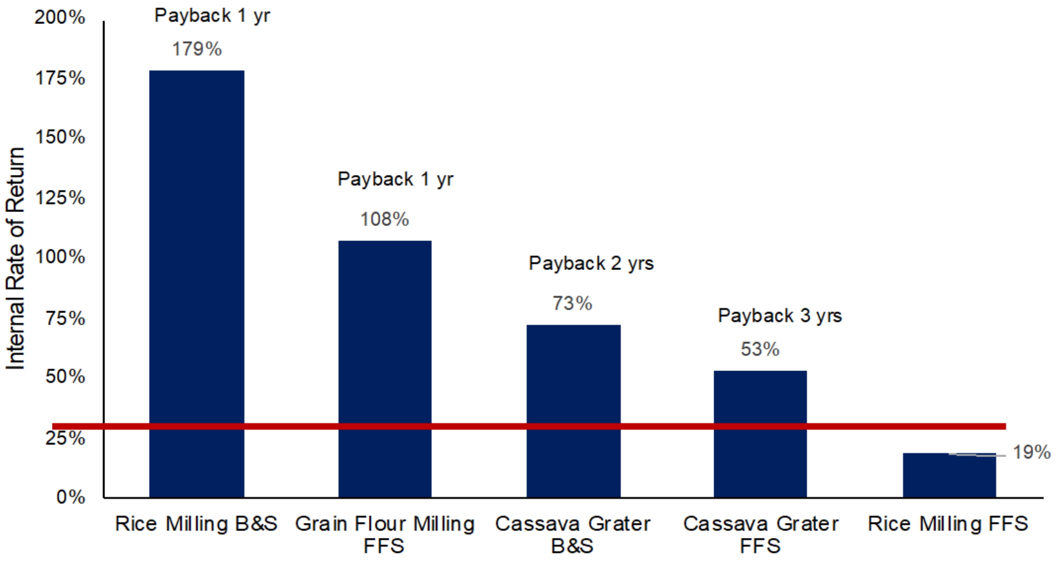


Red line indicates a 30% cost of capital for reference.

Small-scale processors purchasing equipment for activities that can recover the market cost of capital need financial instruments to de-risk investment. This can enable PFIs to lend for a longer duration than the 12-month tenor of loans provided today for activities connected to the small-holder agricultural sector.[xvi] On the other hand, small-scale processors purchasing equipment for activities that are not profitable at market rates will also need concessionary funding to reduce the blended cost of capital to affordable levels until perceived risks fall and market rate debt becomes affordable**. Figure 15** illustrates that an affordable blended cost of capital for fee-for-service rice milling is under 19%.[xvii]

This required cost of capital is above the cost of capital provided by existing concessionary funding programs offered to micro and small processors in Nigeria—Bank of Industry offers loans for small-scale processors with an interest rate under five percent.[xviii] Over time, commercial financiers should begin offering reduced interest rates to small-scale processors once sufficient scale and payment history has been demonstrated.

Several financial instruments can be considered to de-risk investment and crowd-in commercial financing:

- ***Senior and subordinated debt.*** Credit lines designated to on-lend to small-scale processors to encourage lending by PFIs.
- ***Partial credit guarantees.*** PFIs in Nigeria lend a low share of their loan portfolios to agriculture and so may be ill-equipped to properly assess risks and serve sectors related to agriculture. In addition to targeting the few PFIs that do lend to the agriculture sector (see **Section 6.3**), partial credit guarantees can de-risk lending to small-scale processors connected to the agriculture sector and attract additional sources of commercial financing.

[xvi] LAPO Microfinance Ltd. has one of the largest agriculture loan portfolios for small-holder famers and offers loan tenors of one to 12 months. Bank of Industry has tenors of six to nine months for loans it offers to small scale processors under the GEEP program (from stakeholder interviews March 2020).

[xvii] These internal rates of return are based on the economic viability analysis presented in **Section 4**.

[xviii] Interview with representative of Bank of Industry's GEEP program in November 2019 and March 2020. Bank of Industry charges higher interest rates (10 to 15 percent) for loans in other programs.

- ***Life Insurance***. As opposed to the credit guarantee which covers loan repayment in the event of a loan default, life insurance would cover the loan repayment in the event of the small-scale processor's death. Life insurance would reduce collection costs and credit risk and would further de-risk loans to small-scale processors.
- ***Grants for funding initial set-up costs and capital cost reduction.*** Initial coordination, preparation, and studies are needed to connect actors through workshops, fund pilots to test, identify, and standardize suitable equipment to connect to mini-grids, and conduct monitoring and evaluation to demonstrate the success of and lessons learned from pilots and programs. Grants are suitable for financing set-up costs and pre-investment studies because these investments do not offer an immediate and direct financial return to the investor, but they are critical to attract commercial financing later.

These instruments are described in further detail in **Appendix E.**

6.2 ESTIMATED FUNDING REQUIRED

To jump start electrification of productive use alongside mini-grids for priority activities will require substantial investment, but the total amount is within the capabilities of existing funding programs. It is estimated that the investment required to implement Tier 1 activities is under **$30 million**. A detailed explanation of the methodology and assumptions used to develop this estimate is included in **Appendices E.2** and **E.3.**

It is assumed that small-scale processors will lack funding to contribute to a borrower's deposit, and therefore the total funding required from commercial debt and grant sources is equal to the total funding required. Just under half of the funding needed, approximately **$13.2 million**, would be sourced with grant funding and the remaining **$14.3 million** would be financed with commercial debt. To calculate the breakdown of grant to debt funding the study assumed the following components are funded with grant funding: the proportion of the FFS rice mill investment and corresponding fees and operating expenditures needed to achieve a highly affordable blended cost of capital (assumed as 3.75%) for FFS rice milling plus pre-investment costs.[xix] The remaining required investment is funded with commercial debt.

This discussion focused on funding required to deploy Tier 1 activities to focus attention on quick-win opportunities. Investing in these areas will deliver impact in the short- to medium-term and will help guide future efforts for financing electric equipment purchases in other applications. However, as discussed in **Section 3,** Tier 2 activities hold significant potential but will require additional barriers to be overcome before they are commercially viable and ready to implement. Additional funding is required to support these activities and scale agricultural productive use electrification across a larger set of uses in Nigeria.

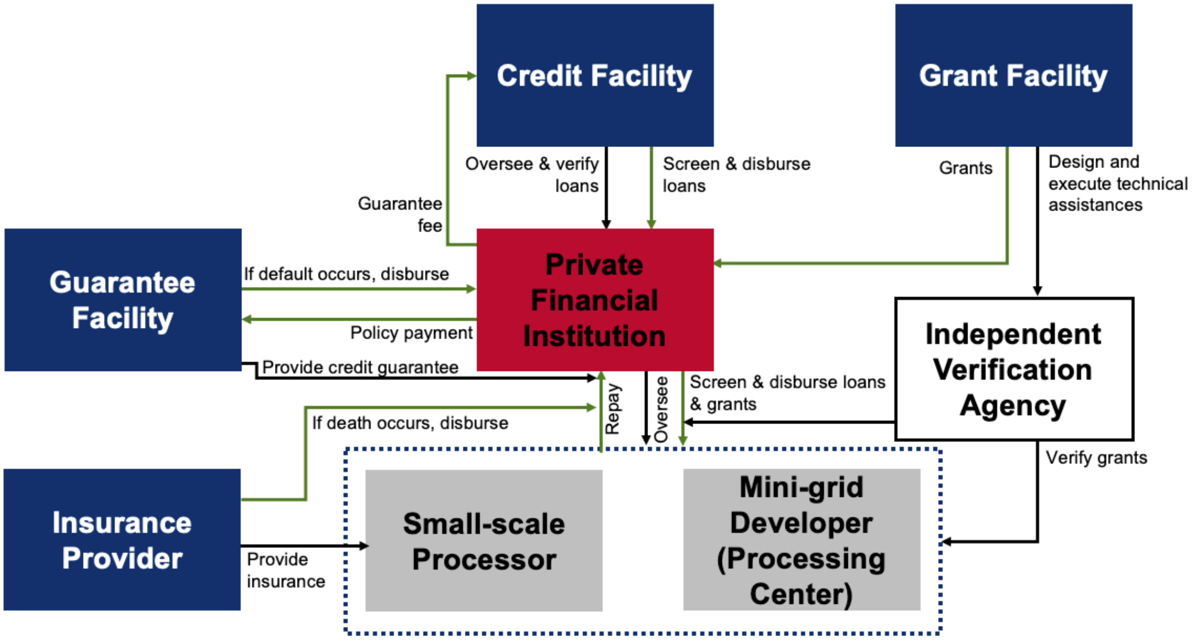
6.3 INSTITUTIONAL ARRANGEMENTS TO FUND EQUIPMENT PURCHASES

Whereas the business models described in **Section 5** focus on the interactions and responsibilities needed to enable equipment purchases, this section defines the supporting structures, interactions, and funding flows necessary to make those business models possible—the deployment strategy. Implementing the deployment strategy identified here will require a set of interactions and funding flows between a number of different institutions. Working together, they can de-risk investments to unlock commercial financing and reduce the blended cost of capital so that small-scale processors can afford equipment purchases.

[xix] This is the average interest rate charged by the Bank of Industry in its GEEP program targeted toward providing access to credit to small processors, traders, and small holder farmers.

Figure 16 shows the proposed institutional arrangement required to make funding available for electrifying Tier 1 agricultural productive use equipment. Specifically, a **credit facility, credit guarantee facility,** and **insurance provider** provide credit lines, credit risk guarantees, and life insurance to unlock loans from **PFIs**. Meanwhile a **grant facility** provides grant financing and technical assistance to reduce the blended cost of capital and fund the pre-investment stage, with verification by an **independent verification agency**. These funds then pass to either the **small-scale processor** or **mini-grid developer** for equipment purchase, as described in the Facilitator and Processing Center business models in **Section 5**. The remainder of this section describes the roles of each actor involved in providing and receiving funding flows in detail and identifies potential candidates who may be well-suited to play these roles.

Figure 16: Institutional Arrangement and Flow of Funds Within the Proposed Deployment Strategy



Grant Facility. This facility provides matching grants to reduce the blended cost of capital and funds technical assistance. Under the institutional arrangement shown in **Figure 16,** the grant facility could issue matching grants to PFIs to reduce the cost of capital for equipment purchases that do not generate enough revenue (FFS rice milling). The grant facility would also fund an independent verification agency to verify the grants provided for these specific applications, and would also fund technical assistance needed for set-up and to conduct pre-investment analysis.

In Nigeria, the Rural Electrification Agency (REA) is well positioned to operate the grant facility, potentially leveraging the project management structures established for the Nigeria Electrification Project (NEP) or for the Rural Electrification Fund (REF). The grant facility would need to access concessional funding from development finance institutions, or taxpayer funding from the state or federal government budgets.

Credit Facility. This facility lends senior and subordinated debt to PFIs to de-risk investment. Possible candidates to fund and/or operate the credit facility include the Development Bank of Nigeria (DBN) and international funders like the International Finance Corporation (IFC):[xx]

[xx] In the past, NSIA has targeted larger scale investments. For instance, in 2013 NSIA invested in the Fund for Agricultural Finance in Nigeria (FAFIN) which supports SMEs in the agriculture sector with revenues of around US$1 million (Source: Expert interviews). Investing in mini-grid development alongside productive use initiatives could

- *DBN* may be particularly well-suited to this role, as its aim is to increase the availability of finance for micro, small, and medium enterprises (MSMEs) in Nigeria by financing intermediaries.[xxi] This mandate aligns with financing electric equipment purchases by small-scale processors. DBN also provides Naira denominated debt with long tenors (up to five and ten years) which is suitable for the required loan durations needed to align with the paybacks shown in Figure 15. DBN cannot control who the PFI lends to, but it can develop products tailored to meet the needs of the facilitator and motivate the PFI to on-lend to facilitators serving small-scale processors. For example, by providing loans at interest rates suited to the sector it intends to target.[xxii]
- *NSIA* may be well-suited to contribute to supporting the Processing Center Model, where it could invest in both mini-grid development and finance electric equipment purchases. The NSIA aims to support economic development through three pillars: building a savings base for times of economic stress, developing a savings base for future generations, and investing in domestic infrastructure that can support economic development. The third pillar is implemented through the Nigeria Infrastructure Fund, which has a Five-Year Plan including investment in energy infrastructure and agriculture.[xxiii]
- The *IFC Global SME Finance Facility* (IFC Finance Facility) could contribute to or operate the credit facility, as it provides investment and advisory services to financial institutions serving MSMEs. Furthermore, its goal aligns closely with financing electric equipment for agricultural productive use as it aims to reduce the financing gap MSMEs face in developing countries. The IFC Finance Facility offers PFIs senior and subordinated loans as well as advisory services, guarantees, and performance-based rebates. In fact, the IFC Finance Facility has invested in Nigerian PFIs before, providing both financial advisory services to improve their capacity to lend to MSMEs and loans to on-lend to MSMEs.[6]

Private Finance Institutions. PFIs receive financing from the credit facility that they on-lend to the small-scale processor or mini-grid developer. The role played by PFIs is key to the deployment strategy, as they are the ultimate lender to the equipment investor. The type of PFI best suited to fund the Facilitator and Processing Center Models would be different. A PFI for the Facilitator Model would need to include financial institutions with a mandate or programs that support financial inclusion and so have the systems and administrative capacity to oversee smaller loans to small-scale processors. In contrast, loans provided to a mini-grid developer under the Processing Center Model could be provided by commercial banks targeting larger customers. Both sets of PFIs should ideally already be lending to the agriculture firms working in upstream activities close to cultivation and with knowledge of how to assess and manage risks common in small-holder farming (e.g., weather, sickness, etc.). The credit facility may also have specific requirements to allow lending to a PFI and to ensure that financing reaches small-scale processors and mini-grid developers. For example, DBN can only lend to organizations that are regulated by the Central Bank of Nigeria. The following are examples of PFIs that may be suited to on-lend to small-scale processors under the Facilitator Model:

- *Bank of Industry (BOI)* may be well-suited to serve this role, as their Government Enterprise and Empowerment Programme (GEEP) already provides affordable loans to micro-processors charging 2.5 to 5 percent interest rates and does not require collateral. As is, the loans provided by GEEP may be too small and tenors too short to purchase electric agricultural processing equipment, as they range in size from N10,000 to N300,000 (around $30 to $900) and loan duration is capped at nine months. However, expanding the GEEP to increase the permitted loan

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enable larger scale investments that could attract NSIA as a partner. Nonetheless, we have prioritized the other possible candidates due to NSIA's suitability as a funding partner for only one of the business models.

[xxi] DBN website: https://www.devbankng.com/who-we-are

[xxii] Interview with DBN in February 2020.

[xxiii] NSIA website: https://www.nsia.com.ng/investments/nigeria-infrastructure-fund

size and extending the loan duration would make BOI an ideal fit for this role, as its main lending requirements are assurance that its investment will be returned and co-financing to support the investment. Both requirements are addressed in this deployment strategy by the credit risk guarantee facility, insurance provider, and credit facility that on-lends to the PFI. BOI also stated their willingness to assess developing a new loan product under the GEEP program to suit the needs of the deployment strategy.

- *LAPO Microfinance Bank Ltd.* (LAPO) may also be well suited to serve this role, as it has a small-scale agriculture loan portfolio that finances farming activities with loans suited for agricultural investment: flexible repayment schedules that align with the seasonal nature of cultivation, no collateral is required, and low interest rates. LAPO also has a higher loan ceiling than BOI's GEEP as they offer loans of up to N500,000 (around $1,400), which is high enough to afford cassava graters and grain flour mills. But their loan duration is also short, ranging from one to 12 months with a grace period of 30 to 60 days.[xxiv] Increasing LAPO's loan duration periods would make LAPO another ideal candidate, as they work closely with borrowers to offer financial advice and may be able to serve a dual role of facilitator and PFI in communities where they have a strong presence.

Credit Guarantee Facility. This facility offers partial credit guarantees to backstop the PFI's loans to reduce credit risk and enable the PFI to offer loans. Various options for guarantee providers exist in Nigeria but further engagement and due diligence will be needed to determine which providers might present the best combination of fit and interest. Potential providers might include:

- *Impact Credit Guarantee Ltd*, a subsidiary of DBN, provides guarantees to PFIs that serve as financial intermediaries to lend to MSMEs.[xxv] As a subsidiary of DBN, Impact Credit Guarantee Ltd. has access to DBN's network of microfinance institutions that may be more suitable than larger commercial banks for financing facilitators. For instance, DBN works with LAPO Microfinance Banks. Additionally, Impact Credit Guarantee offers long durations of five years and high coverage rates of around 60 percent. Currently they only offer one product, an individual guarantee for specific transactions, but they group individual guarantees into a larger portfolio guarantee which may be useful for PFIs lending to multiple facilitators or mini-grid developers to reduce processing time and transaction costs.[xxvi]
- *Infracredit* provides guarantees to infrastructure projects in Nigeria with the goal of unlocking long-term financing for commercially viable projects.[xxvii] Notably for the Processing Center Model, Infracredit could provide a guarantee that includes both the equipment purchase and the mini-grid project, reducing the overall investment risk further than a guarantee solely tied to equipment. However, Infracredit backs larger transactions and individual equipment purchases would need to be bundled to develop a larger transaction, which would take time to design and implement.
- *NIRSAL* provides credit risk guarantees specifically for agriculture and agribusiness finance which backstop up to 75 percent of loans for small-holder farmers. However, stakeholder interviews suggest that NIRSAL's approval process can be time consuming, which might be incompatible with the rapid development timeline for many mini-grid projects.

Insurance provider. An insurance provider provides life insurance to repay the equipment loan in the event of the death of the small-scale processor. There are various insurance providers that offer life insurance in Nigeria. BOI's subsidiary, BOI Insurance Broker's Ltd., provides insurance services, and LAPO

[xxiv] LAPO Microfinance Bank Ltd. Website: https://www.lapo-nigeria.org/loans/agricloan

[xxv] DBN website: https://devbankng.com/partial-guarantee

[xxvi] Interview with representative of Impact Credit Guarantee Ltd March 2020

[xxvii] Infracredit website. https://infracredit.ng/about-us/

provides insurance to its borrowers through third party providers.[xxviii] Grant funding may need to be made available to cover the insurance premium charged up front to the policy holder.

Small-scale processor or mini-grid developer. Under the Facilitator Model, a small-scale processor with support from the facilitator applies for financing to purchase the electric equipment. The loan would be deposited by the PFI into the account of the small-scale processor, and the PFI would implement controls to ensure that the small-scale processor cannot use financing for purposes other than the equipment purchase. PFIs targeting micro-entrepreneurs, like BOI's GEEP, have expertise developing disbursement systems that embed controls like these. Under the Processing Center Model, a mini-grid developer would apply for financing to purchase electric equipment. **Appendix D** presents the role of these actors, required attributes, and potential candidates.

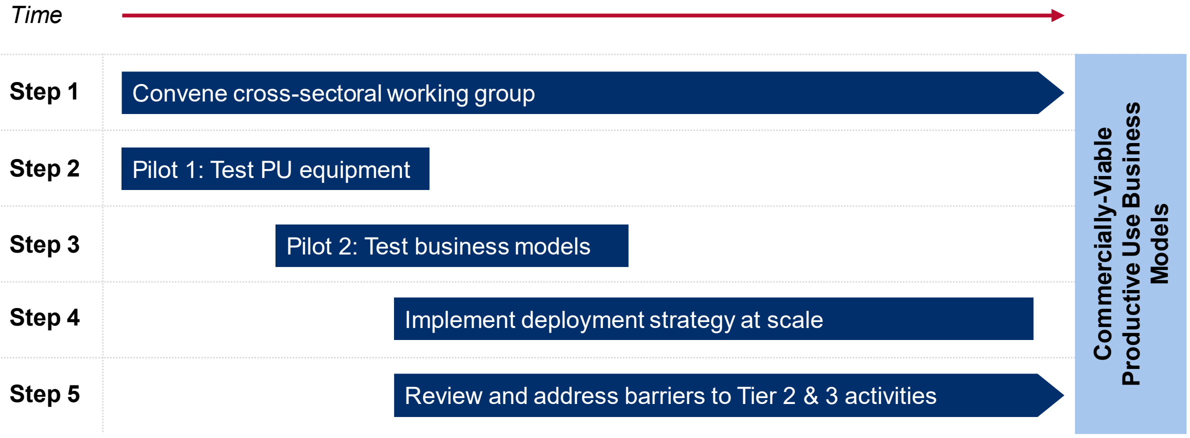
An important consideration across the recommended institutional arrangements is the inclusion of multiple funding streams originating from different financial institutions. Each of these funders will have their own requirements for borrowers or beneficiaries to meet, complicating the application process that the borrower will face. To combat this, a single application portal should be established through the PFI. This application can include the various information requirements that both the PFI and grant facility require. This would not preclude the grant facility from establishing specific criteria for grant approval and would enable it to delegate screening and approval to the PFI or choose to carry out their evaluation separately in parallel. However, both approval processes should be coordinated through the application portal to simplify the process for the applicant.

[xxviii] BOI website: https://www.boi.ng/subsidiaries/boi-insurance-brokers-limited/ and LAPO website: https://www.lapo-nigeria.org/insurance

7 RECOMMENDATIONS FOR ACTION

This section lays a roadmap toward a future where all commercially-led mini-grid projects in rural areas are developed including an agricultural productive use component. Based on this study, there are clear Tier I agricultural activities to prioritize and business model options that will enable equipment purchases. These business models include significant private sector participation to align with the private-led approach of the Nigerian energy sector and to reduce dependency on funding from short-lived donor projects, ensuring long-term sustainability. But jumpstarting deployment requires proof points demonstrating returns of equipment purchases and feasibility of business models to de-risk and attract private investment.

Figure 17: Roadmap to Deploy Productive Use in Mini-Grid Projects in Nigeria With Illustrative Timeline



The roadmap shown in **Figure 17** delivers these proof points through a combination of cross-sectoral engagement across the agriculture and electricity sectors alongside a series of pilots to test the findings and approaches identified in this study. There are five key steps in the roadmap:

1. **Convene a working group across the agriculture and energy sectors** to coordinate, guide, and promote near-term activities required to achieve long-term commercial viability.
2. Implement **phase-one pilots to test equipment** for Tier I activities and collect operational data to refine financial models.
3. Use phase-one pilot data to design and implement **phase-two pilots to test recommended commercial business models** and develop financial instruments.
4. Use the lessons learned from both pilots to refine and implement the deployment strategy, formalizing the structures needed to **finance and support widescale equipment rollout for Tier I activities in mini-grid projects**.
5. In parallel with deployment of Tier I activities, **begin addressing identified barriers to Tier 2 and 3 opportunities** in partnership with working group stakeholders.

The remainder of this section provides greater detail on each of these steps, including the objective, activities, participants, and estimated timeline, with a focus on the most immediate steps required.

Step 1. Convene cross-sectoral working group to bring actors together from both the energy and agriculture communities to open dialogue and facilitate partnerships to implement the roadmap. Details for this step include:

Activities: Hold a series of workshops with actors to open dialogue, agree on partnerships to implement the roadmap, and coordinate its implementation. Participants should establish a working group that will continue to meet during the implementation of the roadmap

Participants: The series of workshops could be led by REA and the Ministry of Agriculture to embed a direct connection with the pilots in Step 2. Participants should include the candidates identified in **Sections 5 and 6** to fulfill roles in the business model and deployment strategy

Timing: Quarterly meetings for the duration of the roadmap.

Step 2: Design and implement pilots to test equipment ('equipment pilot'), measure equipment performance, capture data, and fine-tune financial models. The pilots would target only **existing processors in mini-grid-served communities** by outfitting them with electric equipment. Some developers have already started doing this, and the pilots can build on those results. The data captured will be used in following steps to identify the right equipment, improve accuracy of financial model, and refine the design of business models and attract a small set of PFIs and small-scale processors to run the business model pilot included in the next step:

Activities: The core action under Step 2 is setting up a data collection and monitoring system to collect and disseminate proof points regarding equipment performance in the field. The key steps in doing so include defining the **data variables** to track, designing and setting up the **data collection and monitoring system** to capture that data, and **logistics of supplying the equipment**:

- Data variables the pilot will collect information used to assess whether PFIs and small-scale processors can recover their investment and defining the right equipment to invest in. This includes hourly smart meter data describing equipment operation, a complete record of costs and revenues for the business (transaction type, price, quantity, expenses), and equipment specifications (cost, capacity). Customer satisfaction surveys can capture opinions of equipment operators and patrons. PFIs can use this information to design suitable financing instruments (loan size, interest rates, repayment schedule), and small-scale processors can use it to determine whether to invest in equipment and which to invest in.
- The data collection and monitoring system should fulfill the following key responsibilities:
    - *Pilot oversight, capacity building, and data analysis*: Lead and oversee pilot implementation, develop the system to deliver data, train field team on the data collection system and practices, and consolidate, organize, and analyze data.
    - *Equipment selection and supply*: Identify the equipment to test for suitability against equipment operator and patron preferences and mini-grid compatibility. Deliver equipment to selected communities and small-scale processors.
    - *Community selection and data collection*: Select community, describe the pilot and its purpose to community, select and train pre-existing small-scale processors on using equipment and collecting data, monitor use of equipment, and oversee data collection.
- Logistics of equipment supply and other design features can deploy equipment for Tier 1 activities to a sample of existing small-scale processors in mini-grid sites at no cost to ensure the timeliness of implementing the equipment pilot. This would include select communities in each of the three major agroecological zones in Nigeria to achieve a representative understanding of equipment performance and inform a national-scale program. Where possible, it is

recommended to equip multiple processors of the same type within a given community (e.g., multiple rice millers). Sites should be chosen in consultation with state ADPs who can inform which communities receive extension services for the Tier 1 crops.

Participants: The data collection roles are most critical to fill. Example organizations include:

- *Pilot oversight, capacity building, and data analysis*: An organization like REA could fill this role, with experience implementing many development projects and the proven management capacity to oversee the equipment pilot
- *Equipment selection and supply:* AMEFAN, national research institutes, and state ADPs could each bring technical expertise to identify equipment that meets local needs. Mini-grid developers meanwhile can identify equipment compatible with their systems.
- *Community selection and data collection*: REA regional offices and state ADPs are well positioned to manage a cross-sectoral field team to support this role.

Timing: The pilot should have duration close to one year to capture a complete understanding of volumes, usage, and cost recover across seasons, but initial insights can be used to begin Step 3 before the pilot is fully complete.

Step 3: Design and implement a second set of pilots ('business model pilots') to recruit private actors to implement recommended business models around Tier 1 activities and demonstrate financial viability, with a primary objective of evaluating whether revenues can recover the costs of operating the business model.

Activities: Completing Step 3 will include **integrating equipment pilot results**, **designing business model pilots**, and **disseminating results** to secure partnerships:

- Assess results from the equipment pilots on operator and patron preferences and mini-grid compatibility in order to define specifications for suitable equipment, and build an equipment catalogue to disseminate among vendors, mini-grid developers, and small-scale processors. Then assess data on costs and revenues in order to fine-tune financial models and refine design of financial instruments.
- Design the business model pilot by first securing PFI and facilitator partners and providing funding to test applications of the business models in a sample of mini-grid sites. To attract the PFI and facilitator, the pilot may need to offer flexible financing that mimics the funding provided under the deployment strategy. For instance, the pilot can provide the PFI a loan that converts to a grant if the small-scale processor defaults. The specific number of sites and applications can be defined based on funding available and the number of proof-points investors need to de-risk and unlock commercial financing.

Habibu Lawal with his 25 hp diesel one-stage rice mill in Zagezagi community, Kaduna state, where he reports spending N4600 on diesel alone during a busy day of milling, and an additional N5000 per month for maintenance of the aging motor. This mill yields 50 kg of milled rice for every 100 kg bag of paddy rice—new mills can improve quality and boost milling yields by 20–30%.

    - *Data collection and monitoring:* As above, these pilots must include a robust system to capture results. Key data would include the attributes needed to fulfill the facilitator role, situations where the facilitator role is necessary and where it is not, returns each actor requires to recover their costs, and whether the subsidies and revenue flows generated by the model are sufficient to cover those costs.
- Disseminate results, beginning with the cross-sectoral working group, to engage candidates who can build on the business model pilot to implement at scale. This would include sharing updated financial models and a refined version of the proposed deployment strategy.

Participants: A similar set of actors as Step 2 are required, with the addition of a PFI and facilitator partners, along with any additional funding providers needed to round out the business model.

Timeline: The full business model pilot should be in place long enough to capture the full repayment schedule of the equipment loans, which will depend on the funder but is likely to be between two to five years. However, as with Step 2, the next step can begin well before the pilot is fully complete.

Step 4: Implement the deployment strategy to incorporate lessons learned from the two pilots and bring a broader productive use program to scale. This will connect the financing sources needed with now-proven business models, and share the information needed to enable investment in equipment:

Activities: The priority first step will be to confirm a **host to lead the deployment strategy**, and then to establish a **data collection and monitoring** system:

- Identify deployment strategy host, ideally within or alongside an existing donor-funded electrification or agricultural development program. For example, the NEP and Mini-grid Acceleration Scheme (MAS) in Nigeria would be well-situated to integrate the deployment strategy alongside projects they are already supporting. This would leverage existing management structures to quickly operationalize the new program and to coordinate and connect actors in the deployment strategy. Importantly, this would also ensure access to a technical team with expertise to oversee the disbursement of grant funding for qualifying equipment purchases and provide technical assistance.
- Develop and implement a data collection and monitoring system to create the insights and proof points needed to attract additional commercial financing. To collect the most useful data points, this should be carefully designed in consultation with the cross-sectoral working group, particularly including commercial developers and financial organizations.

Participants: A trusted organization like the REA, potentially with operational support from a development partner, could lead the operation of the grant facility as well establish and operate the data collection and monitoring system, and disseminate results. As noted in **Section 6**, there are many possibilities to fill the other roles required within the deployment strategy, and these will need to be defined based on organizations' interest in participating.

Timeline: The deployment strategy can be ongoing for a period of years, or as needed to fully shift funders and implementers to a commercial model. The duration required will depend on the scale and effectiveness of the program—a properly sized and highly efficient program could conceivably accomplish this in a short period of time if the necessary actors are engaged early, made participants in the process, and able to directly see positive results. In contrast, an undersized program that ineffectively engages necessary stakeholders and fails to collect and share critical data may languish.

Step 5: Begin addressing identified barriers to Tier 2 and 3 opportunities, to expand the set of commercially-viable activities available. This can begin in parallel with implementation of the deployment strategy and can focus on the Tier 2 and Tier 3 activities outlined in **Section 3** with a particular focus on those where the identified barriers can be quickly overcome with targeted research.

For instance, stationary, minigrid-tied multi-crop threshers piloted in **Step 2** will likely suit customer preferences for some crops which are easy to transport to the town center (e.g., maize, sorghum, cowpea), but not others which are typically threshed in the fields (e.g., rice). Mobile electric threshers could be built to operate as standalone solar-battery units or as battery-powered units that can be charged at the mini-grid site. A research and development project could design, prototype, and test such devices, which do not exist on the market today. Finally, local manufacturers could be trained to construct the new mobile electric threshers and supply them at scale.

Milk chilling is a Tier 3 opportunity where electric equipment is readily available, but where significant support is required to build local capacity in dairy communities, develop an offtake market, and scale. This productive use of energy could be further developed in partnership with existing dairy offtakers who have an interest in building their local milk supply chain. A program could facilitate partnerships between mini-grid developers in search of anchor loads and commercial dairy processors who have identified potential sites for milk collection operations.

Ayila Augustin Obogo, of Akaraba community, Kaduna state, with his mobile cassava grater. Mr. Obogo is the sole cassava grater in his community of 300 households. He would like to expand his business but cites a lack of financing, business education, and reliable electricity as barriers.

The prospects for electrification in Nigeria have never been brighter. With dramatic cost reductions in sight, and increased attention from government, development partners, and the private sector, energy access technologies are poised to proliferate at breakneck speed. However, it is critical that these projects are accompanied by business models that electrify agricultural productive uses. Failing to do so may compromise project economics and longevity, while an effective deployment strategy will unlock local economic development and can serve as a springboard toward realizing the full potential of rural electrification.

8 APPENDICES

The appendices in this section are a core part of the study and contain the detailed analyses and recommendations to support program design and implementation They are structured as follows:

- **Appendix A** presents an in-depth analysis of the 12 value chains and detailed assessment of where electrification opportunities exist.
- **Appendix B** presents a sample of existing vendors for Tier 1 activities in Nigeria that served as an input for the prioritization analysis and can be built on further to map out the availability of equipment.
- **Appendix C** presents a detailed analysis of the economic viability of Tier 1 activities and explains the methodology and assumptions used to prepare the financial models.
- **Appendix D** provides a deeper look at the business models suitable for Tier 1 and Tier 2 activities, assessing roles and responsibilities and how the models perform in overcoming key barriers. It also identifies a third model suitable for Tier 3 activities.
- **Appendix E** provides in-depth analysis of the type and amount of financing required to implement the business models and explains the methodology and assumptions used to estimate the funding required.
- **Appendix F** presents a streamlined mapping of key actors active in the agricultural and energy sectors in Nigeria.
- **Appendix G** presents the bibliography for the literature review.
- **Appendix H** presents the questionnaire used for field surveys.

APPENDIX A IN-DEPTH VALUE CHAIN ASSESSMENTS

This appendix analyzes 12 target value chains to identify opportunities for productive uses of mini-grid electricity using the methodology described in **Section 2.3**. The appendix focuses on post-harvest operations: the processing steps from farm-gate material to the locally marketed product. We analyze each value chain in detail to identify opportunities to electrify value-add activities. Using four criteria – Local Capacity, Offtake Market, Electric Equipment, and Scalability – we sort these opportunities into three tiers based on the amount of support required to electrify them. **Table 3** presents these classifications for each activity and crop considered. **Appendices A2–A13** provide in-depth analysis on each value chain, while **Appendix A.1** analyzes trends across the target value chains.

A.1 *Cross-Value-Chain Analysis*

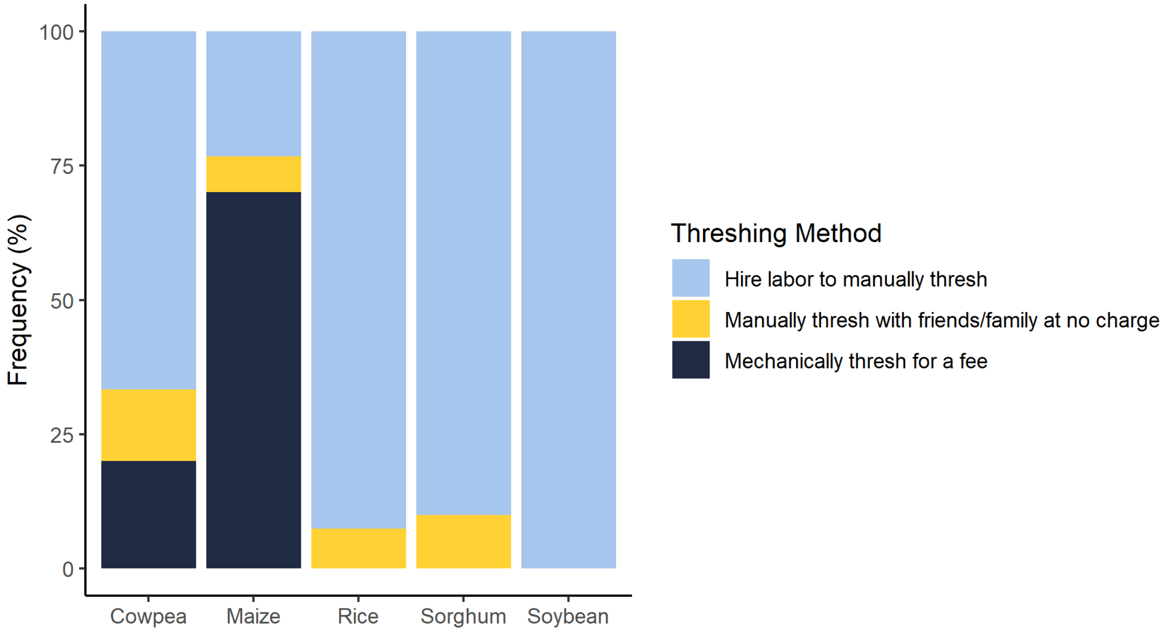
In this section we consider the role of multi-crop processing equipment in enhancing the viability of investments in electrical threshing and milling. We also provide a brief discussion on the viability of mini-grid-powered irrigation.

A.1.1 Multi-Crop Threshing

Threshing is the process of separating dry grains from the grass, stalk, or pod in which they grow. Farmers who harvest crops by hand typically dry the grains and then thresh and clean the grain before sale or further processing. In fully mechanized production, combine harvesters can perform harvesting, threshing, and winnowing in one step.[7]

Mechanized threshers are useful for crops that are manually harvested but for which manual threshing entails high labor costs or degrades grain quality. These crops tend to be dry cereal grains that are grown in high volumes: maize, rice, cowpea, soybean, and sorghum**. Figure 18** shows the threshing practices reported by farmers for these grains in our field surveys. A multi-crop thresher, such as the Soybean Innovation Lab's prototype, can process maize, soybean, rice, sorghum, cowpea and common beans 80% faster than manual threshing, with near-zero losses.[8]

Figure 18: Threshing Practices Reported by Farmers for Five Surveyed Value Chains



Most farmers already hire labor for threshing each harvest season, showing some ability to pay for mechanical threshing. Farmers' interest in a centralized threshing scheme (as would be suited to mini-grids) varied widely from crop to crop. 20% of rice farmers "strongly agreed" that they'd be willing to adopt a centralized threshing model, compared to 100% of cowpea farmers. However, customer willingness to pay for this service, after accounting for transport costs, is unknown. Comments from field enumerators indicate that even if mechanical threshing is available, farmers will typically choose the cheaper of the two options between manual and mechanical threshing. Farmers may be willing to pay a slight premium for mechanical threshing if it demonstrably decreases grain losses and improves cleanliness of threshed product. Centralized threshing models may also facilitate bulk drying and hermetic packaging, which are key to minimizing post-harvest losses (as discussed in **A.3.1.1, A.9.1.1, and A.10.1.1**).

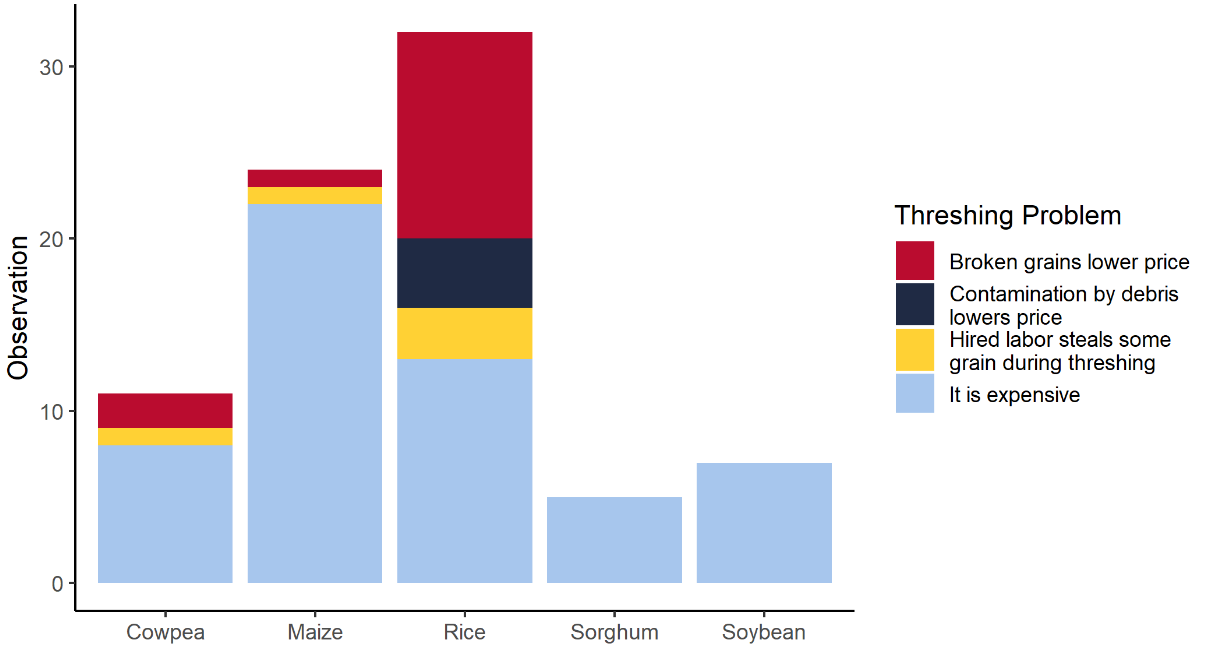
Compared to cowpea, sorghum, and maize producers, soybean and rice farmers expressed more skepticism towards mechanical threshing in a centralized location. The general pattern is that **farmers are less inclined towards a centralized mechanical threshing model when their crop is harvested as a whole plant (e.g., soybeans, rice) compared to crops where it is possible to remove only the food-bearing portion (e.g., maize, sorghum, soybeans)**.

Except for maize, most crops are still manually threshed in the communities we surveyed. But traditional threshing practices are widely documented to require many human-hours per unit volume, and to degrade the quality of the final product by incorporating debris or breaking grains (see crop-specific threshing analyses in **Appendices A.3.3, A.4.3, A.9.3, A.10.3, and A.11.3**). **Figure 19** tabulates farmers' complaints about their threshing practices, showing cost to be a major concern. Rice farmers are especially likely to report that grain damage and contamination reduce the quality and selling price of their paddy rice. It is uncertain whether higher quality threshed grain will fetch a higher sale price in local markets. In interviews, industrial offtakers expressed concern that because of lax grading standards at the local level, high-quality grain is often mixed with lower-quality product before final sale. Thus, offtakers offer low price premiums (on the order of 5%) for mechanically threshed grains.

The business case for mechanized threshing depends on processing volume.

Mechanical threshers' processing fees are capped by two key factors: 1) they must compete with manual threshing alternatives, and 2) the price premium for mechanically threshed grains is currently low. In addition, the seasonality of the grain harvest and interannual fluctuations in production make it difficult to anticipate the capacity utilization of this equipment over its life.

Figure 19: Problems Experienced During Grain Threshing, as Reported By 91 Farmers in Cross River and Kaduna States



The business model for a centralized thresher depends on the volume that the thresher can process throughout the year. The Soybean Innovation Lab's multi-crop thresher costs roughly $2,000, while a median farmer spent roughly $10 to thresh a season's grain harvest. If the thresher processes 20 typical farmers' harvest per year, then the simple payback on the machine is roughly 10 years. **If the thresher can serve 100 farmers, then the payback reduces to around 2 years.** Because most mini-grid-suitable communities cultivate a variety of cereal grains, multi-crop threshers are best positioned to realize the capacity utilization required to justify the initial investment.

Without pilot testing, it is unclear whether multi-crop threshers in mini-grid-suitable communities can achieve sufficient volume to sustain operations.

Mini-grid threshing pilots can further test the business model for stationary electric maize threshers to ensure that local farmers can meet volume requirements and that customers are willing to pay fees that can justify the cost of owning and operating the equipment. Mini-grids that own and operate threshers may be able to use excess peak solar power to keep operating costs close to zero, improving the likelihood that customers can be served at an agreeable fee.

A.1.2 Multi-Crop Milling

Most mini-grid-suitable communities in rural Nigeria already host small grain flour millers who convert maize, sorghum, cowpea, soybean, and other local crops into flours and meals used to make staple foods. Today these mills are fossil-powered, typically utilizing old, oversized combustion engines as the prime mover. Electric engines offer clear savings on operation costs over the status quo (**Section 4**). Standalone solar PV mills are in pilot stages but are unlikely to be cost-competitive with plug-in or fossil-powered mills in the near term, especially in Nigeria where new electric mills must compete with incumbent mills in most mini-grid-suitable communities.[5]

The payback period for an electrified flour mill is largely dependent on the volume of grain it can process each year. Like multi-crop threshers, grain mills that can process multiple kinds of products are more likely to realize the volume required to sustain operations.

Details matter: customer preferences for end product characteristics must be satisfied by the selected mill.

When selecting the type of mill (e.g., hammer, plate, disc), customer preferences for flour fineness, taste and consistency must be the foremost consideration. Customers will only patronize new electric mills if their quality criteria are satisfied, and the service is offered at a competitive price. For a multi-crop mill, this may involve complex trade-offs between crops. For instance, a disc mill that grinds soaked, dehulled cowpeas into a paste for *akara* may not be suitable for maize meal production without a thorough cleaning between products to rid the discs of cowpea's "beany" odor.

Pilots should test viability of different multi-crop mills and their ability to achieve viable processing volumes in mini-grid communities.

Entrepreneurs or mini-grid companies considering entering the market as a milling service provider should consider their ability to meet customers' tastes, in addition to the operating cost considerations for their mill model. In the near term, we recommend piloting smaller flour mills that are more likely to meet capacity utilization targets, than larger flour mills that may cost less on a $/kg-hr throughput basis but will be more difficult to pay back.

A.1.3 Mini-grid-Powered Irrigation

Irrigation would boost primary production of nearly every crop discussed in our in-depth value chain analyses. Analysis in **Box A.5** shows that electric pumps beat operating costs of diesel alternatives by 25% at mini-grid electricity prices. However, **the viability of irrigating local fields with mini-grid-powered pumps depends on the balance of additional electricity revenue with any distribution costs** associated with connecting the pumps to distant fields.

Our data show that irrigated fields are typically far from the community center where mini-grid distribution lines will be located (**Table 8**).

Table 8: Farmers' Responses When Asked About the Distance Between Their Fields and Community Center

To farmers: How any minutes would it take you to walk from your farm to the community center? *(n = 78)*	
Response	*Frequency*
1–15 minutes	8%
15–30 minutes	41%
30–45 minutes	28%
>45 minutes	23%

Assuming a four mile-per-hour walking speed, these data put 90% of farms more than a mile from the city center, which is beyond the service territory for most mini-grids. It is unlikely that most fields can be served by mini-grids at lower cost than standalone solar or fossil pumps, which are already commercially available. A notable exception may be clusters of farms, or a commercial operation, which have a large water demand — but careful due diligence would be required to evaluate each opportunity on a case-by-case basis. Water pumping loads closer to the community center, such as ground wells ("boreholes") or aquaculture circulation systems, may be more attractive loads to power via mini-grid.

A.2 *Cassava*

- **Cassava is a critical staple food grown at high volumes throughout Nigeria.**
- **Nearly all cassava is mechanically processed before consumption.** Cassava tubers are highly perishable in their raw form and must be processed within 24–72 hours of harvest. In mini-grid-suitable communities, there is substantial local capacity to meet this processing demand.
- **Cassava grating is a leading candidate for electrification.** Nearly all cassava products require peeled roots to be grated into a soft mash amenable to further processing, and nearly all grating is mechanical in Nigeria. The diesel lister engine is the costliest part of the mechanical grinder, and there is potential opportunity to displace fossil fuels while saving on fuel cost.

A.2.1 Crop Background and Market Characteristics

A 2010 assessment by UNIDO rates cassava as the agricultural value chain with greatest development potential in Nigeria.[9] The tuber is a staple food crop in the country, which leads the world in production at 55 million metric tons per year, grown by 30 million farmers.[10] A cheap source of carbohydrates, cassava is Nigeria's top staple crop but is a poor source of other nutrients.

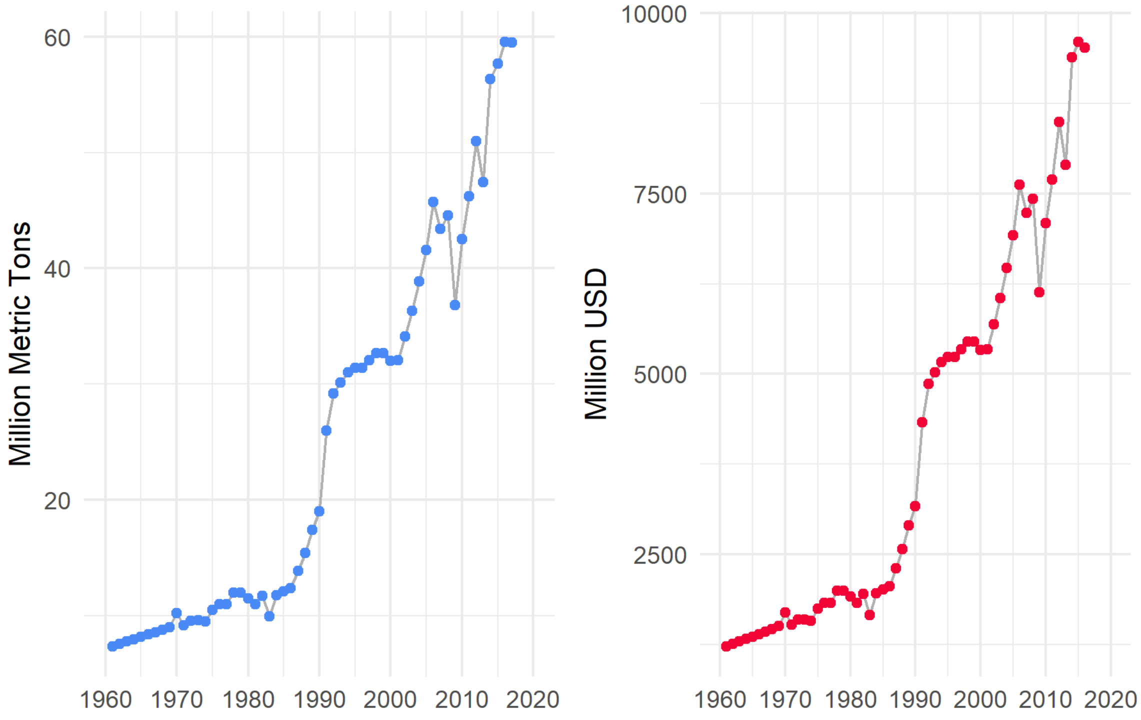
The plant performs well in sub-optimal soil and rainfall conditions and is a perennial with a very wide harvesting window. Cassava is produced across virtually all of Nigeria's agro-ecological zones, but the top ten producing states in the south and central belt (Cross River, Kaduna, Kogi, Benue, Enugu, Imo, Ogun, Ondo, Taraba, Anambra, Oyo) account for 63% of production.[11] In our survey, 93% of communities in Cross River cultivated cassava, but communities visited in northern Kaduna did not.

Margaret Matiki peeling cassava in the shade in Egoja-Ndim community, Cross River state.

Smallholder cassava yields are low relative to the global average – just 2.5 t/ha on a dry mass basis compared to nearly 7 t/ha achieved in southeast Asia using best practices.[10] Per-area production has not shown much improvement in the past 50 years,[12] but Nigeria's total cassava production has risen steadily as production has spread to occupy increasing amounts of land (**Figure 20**). Cassava has a highly flexible cultivation cycle: left unharvested, healthy plants will keep growing tubers for years.[13]

Cassava farming is a nearly $10 billion dollar industry in Nigeria, which produces an estimated 60 million metric tons of the tuber each year.[10] The Nigerian cassava value chain is extremely complex and the crop can be processed into hundreds of different final products.[14] However, 85–90% of cassava goes to a few processed foods: *gari* (a toasted granular meal), *fufu/akpu/lafun* (fermented pastes) and cassava starch. These dishes are central to the Nigeria diet: one report claims that four out of five rural Nigerians eat a cassava-based meal at least once per week.[15]

Figure 20: Gross National Production (Left) and Farm-Gate Value (Right) of Nigerian Cassava[10]



The remaining 10–15% of Nigerian cassava is processed industrially, most often chipped and integrated into animal feed. The IITA has also developed a process for converting cassava peels into a high-quality livestock feed,[16] but most cassava peelers we interviewed had not monetized their peelings.

There are nascent industrial markets for high-quality cassava flour and cassava fuel ethanol, but prospective communities for off-grid mini-grids are not commonly connected to these supply chains. It is possible that local mini-grid communities might supply cassava chips to these industrial supply chains in the future, but today such opportunities are rare. See **Box A.2** for further discussion.

A.2.1.1 Post-Harvest Losses

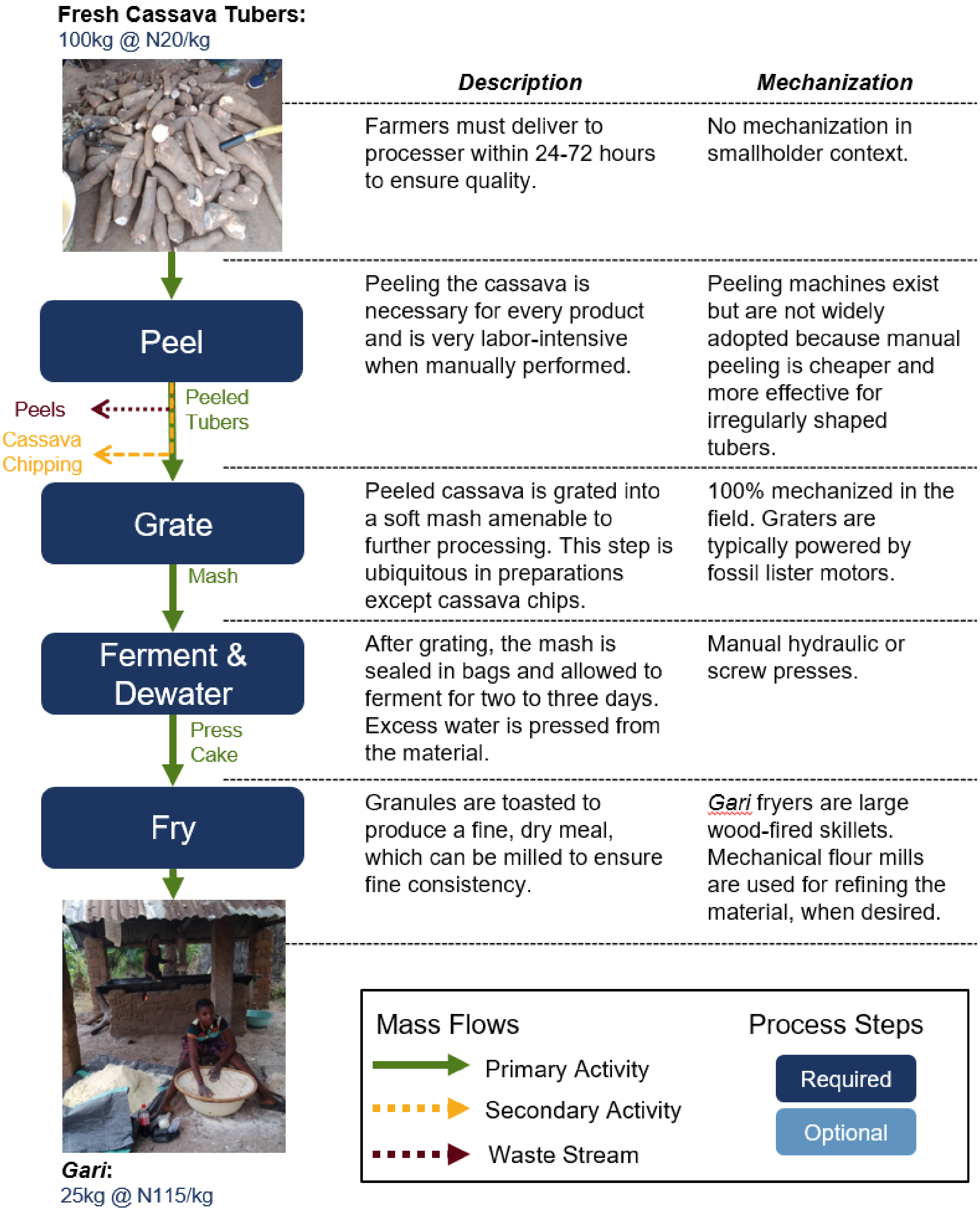
Cassava tubers are living organs. Once removed from the plant, the tubers continue to metabolize and deteriorate quickly.[14] This perishability limits shelf life to less than three days, meaning that raw tubers must be quickly consumed or processed into shelf-stable staples such as gari, which can be stored for 6 months or more depending on storage conditions.[9] The losses during this phase of the value chain can be quite high, especially if bottlenecks in transport or local processing capacity occur, leaving raw tubers to spoil in post-harvest storage.

After cassava has been transformed into *gari* or starch, only 6–7% of the final product is lost during storage[17]. Because cassava products have been developed as methods to prolong shelf-life, these post-harvest losses are low relative to other crops, such as maize, which can lose over 25% of the product during the marketing stage. In general, the higher the processing capacity of local communities, the lower the risk that cassava will spoil during its limited (~24 hour) window from harvest to processing. This natural requirement for local processing makes the crop a strong candidate for value chain electrification via mini-grids.

A.2.2 *Value Chain Description*

We focus our cassava value chain analysis on *gari* production, which is an important food across all of Nigeria's geographical regions.[18] Of the 40 cassava actors we interviewed in Kaduna and Cross River states, 80% were engaged primarily in farming and processing cassava to produce *gari*, or in trading *gari* itself. **Figure 21** describes each step in *gari* production.

Figure 21: Value Chain Summary from Fresh Cassava to *Gari*

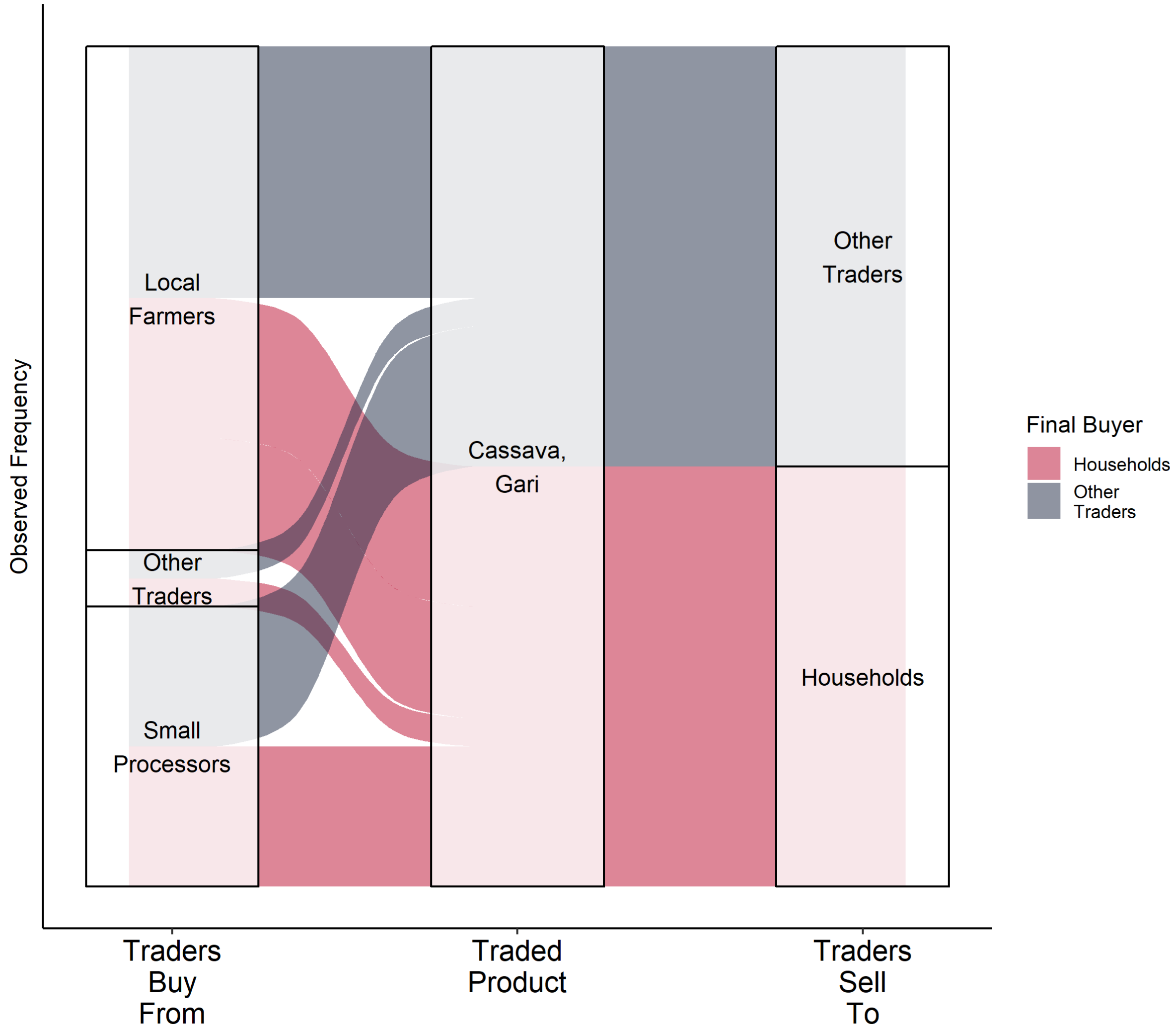


Description	*Mechanization*
Farmers must deliver to processer within 24-72 hours to ensure quality.	No mechanization in smallholder context.
Peeling the cassava is necessary for every product and is very labor-intensive when manually performed.	Peeling machines exist but are not widely adopted because manual peeling is cheaper and more effective for irregularly shaped tubers.
Peeled cassava is grated into a soft mash amenable to further processing. This step is ubiquitous in preparations except cassava chips.	100% mechanized in the field. Graters are typically powered by fossil lister motors.
After grating, the mash is sealed in bags and allowed to ferment for two to three days. Excess water is pressed from the material.	Manual hydraulic or screw presses.
Granules are toasted to produce a fine, dry meal, which can be milled to ensure fine consistency.	*Gari* fryers are large wood-fired skillets. Mechanical flour mills are used for refining the material, when desired.

A.2.2.1 LOCAL CASSAVA TRADE

Figure 22 summarizes the *gari* market flows as reported by local traders. Of the communities we surveyed, *gari* was the only prominent marketed product. Traders buy *gari* mainly from local processors, some of whom are farmers themselves. The *gari* is then distributed roughly evenly between other traders who take the *gari* outside of the community, and local households who consume it.

Figure 22: Summary of Local Trade Flows Reported in Field Surveys



Flow size is proportional to the likelihood of the trade: about half of the time gari is sold to households as the final buyer.

These trade flows demonstrate a strong demand for locally produced *gari*, which ensures an offtake market for local processors. If *gari* processing increases beyond the community demand, we also observe market linkages to other traders beyond the community, giving confidence that increased *gari* production will not be stranded in mini-grid communities even if the local market is saturated. These trade dynamics are a best-case scenario for local value-added products.

A.2.3 Opportunities for Electrification in Cassava Processing

Analyzing key considerations for cassava production activities finds both Tier 1 (cassava grating) and Tier 3 (mechanical cassava peeling and cassava chipping) opportunities. These analyses are below.

TIER 1

Cassava Grating

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant

Local Capacity	●	All cassava-producing communities surveyed had at least one mechanized *gari* processor within the town.
Offtake Market	●	*Gari* and related products are staples with strong local markets.
Electric Equipment	●	Electric cassava graters are available in Nigeria,[xxix] and old graters can be retrofit with new electric motors. After a quality control pilot, these pieces of equipment are ready to deploy at scale.
Scalability	●	The cassava market is widespread throughout the South and Middle Belt of Nigeria and most cassava products require a grating step.

Mechanical cassava graters use a motor and pulley system to spin a grating drum. The peeled tubers are loaded into a hopper and a stick or other prod is sometimes used to maintain contact between the material and grating surface.

Cassava grating can be readily electrified through new electrical graters or electric motor retrofits. Nearly all cassava products require peeled roots to be grated into a soft mash amenable to further processing, and nearly all grating is mechanical in Nigeria. Mechanical cassava grating was present in most cassava-producing communities included in the field survey, all powered by petrol or diesel motors.

The diesel lister engine is the costliest part of the mechanical grinder, and there's potential opportunity to displace fossil fuels while saving on fuel cost. A separate survey of cassava machinery in Oyo state found that at the grid edge, both diesel and electric graters [xxx] were available, and were more likely to be operated by women than diesel graters.[19] **Appendix C.2** presents the business case for a *gari* business as run on electric cassava graters.

Interview respondents speculated that less cassava would spoil post-harvest if new graters were to raise local cassava grating capacity.

Isaac Ibuogbeche with his diesel cassava grater in Woda community, Cross River state. Customers bring peeled tubers that are processed into *gari*. He would like to upgrade his old machine, which costs 2000 N/month ($5.50/month) to service, but he cannot access credit to make the purchase.

[xxix] Bennie Agro Limited (NG) sells an electric cassava grater with 3300 kg/hr capacity, powered by a 7.5kW three-phase motor for N700,000 (~$1,930).

TIER 3

Mechanical Cassava Peeling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◑	Only a quarter of respondents had ever seen a mechanical cassava peeler.
Offtake Market	◕	Peeling is a critical step for all cassava products marketed in Nigeria.
Electric Equipment	◔	Today's small-scale peeling machines[xxxi] have not been widely adopted because they are neither proficient at the task nor cost effective.
Scalability	◑	Limited to processors or communities who process enough cassava to maintain high utilization of mechanical peeling.

Mechanical cassava peeling could improve efficiency of workers but is not preferred by cassava processors. Manual cassava peeling is extremely labor intensive, accounting for an estimated 35% of labor hours in cassava processing operations.[20] However, only one in four cassava value chain actors surveyed had seen mechanical peeling in action, and the process has proven difficult to mechanize. Peeling machines struggle to peel irregularly shaped tubers completely, requiring a manual peeler to follow the machine in many cases. Additionally, small tubers can be completely lost in the process as they are scraped down to nothing before larger tubers are finished. For these reasons, even some equipment manufacturers don't endorse their peelers for most customers.[21] If an appropriately sized electric cassava peeler were able to ensure quality, and available in Nigeria, mechanical peeling may become a more attractive candidate for productive use. However, this would require significant innovation to improve the efficacy and reduce the cost of the machine itself.

Box A.2 Domestic industrial cassava processing could provide large offtake markets, but potential for local electrification is low.

There is a strong case to be made for domestic production of cassava starch, high-quality cassava flour, cassava fuel ethanol, and other highly-processed products.[18] However, industrial processing capacity is currently low and concentrated in large facilities that source from their own plantations or buy raw tubers from outgrower schemes.

To ensure quality of their final products, industrial processors only purchase fresh, raw tubers from aggregators who can sell in bulk. They do not source cassava in any intermediate form, who limits the role of electrification in mini-grid contexts. Additionally, the time sensitivity of raw cassava post-harvest as well as the expense of transporting undried tubers makes it difficult for large processors to source from remote communities[22].

Attempts to localize industrial processing have not been successful. For example, in the early 2000s, the IITA/USAID/Thresh Cassava Enterprise Development Project aimed to establish local cassava flour producers in the Niger Delta region, 90% of these operations had failed by 2011 as the local producers struggled to keep cost low enough to compete with imports and industrial-scale producers.[23]

[xxxi] Goodway (CN) sells an electric cassava peeler with 3300 kg/hr capacity, powered by a 3 kW three-phase motor.

Cassava Chipping

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◕	While not a primary business in the surveyed communities, it is common practice to chip and dry leftover or irregular cassava tubers that are not utilized for food production.
Offtake Market	◔	Local demand for cassava chips is low, but there are potentially large industrial domestic and international markets.
Electric Equipment	◕	Chipping machines are common and simple to manufacture.
Scalability	◔	In today's market environment, commercialization of cassava chipping requires a rare combination of factors: a critical mass of cassava production, an aggregator with a transport network to local farms and quality control capacity, and a final offtaker.

Cassava that is not utilized for local food products may be chipped, dried, and utilized as a carbohydrate source for fuel ethanol or animal feed production.[24] Electric cassava chipping machines are simple to manufacture and widely available, [xxxii] and local drying practices are usually sufficient to achieve the 15% moisture content requirement.

China imports $1 billion of dried cassava per year, accounting for 65% of global imports. [25] Nigeria, however, is not a player in the cassava export market. Southeast Asia — namely Thailand, Indonesia and Vietnam — account for nearly all global exports.[26]

The near-term viability of electrified cassava chipping is limited by market bottlenecks. Local demand for cassava chips is low, but there are large potential domestic markets and international markets. For example, if Nigerian cassava processors could aggregate cassava chip production to a scale on the order of 1,000 tons per month, it is likely that a foreign ethanol producer could be interested in entering an offtake agreement.[xxxiii] However, this level of production is commensurate with aggregation of roughly 200 smallholders producing 3 t/ha on 2 hectares. These farmers may represent a significant segment of the staple food supply in the remote communities in which they live, and without a smooth transition to other market sources of food, these communities may risk acute local food shortages and price spikes. Such coordination between large groups, smallholders, and foreign actors is not within the purview of an initial productive use stimulation program but given the correct stakeholders and offtaker the electrification of cassava chipping could have potential as a new value stream for mini-grids and local entrepreneurs.

[xxxii] NCAM Limited (NG) sells an electric combined grater and Chipping machine with 600 kg/hr capacity, powered by a 3.7kW three-phase motor.

[xxxiii] Interview: Ayodeji Balogun, CEO, AFEX Commodities Exchange Limited, February 2020.

A.3 *Maize*

- **Maize is widely grown and consumed in Nigeria.** 10 million metric tons of production per year flow roughly equally to human consumption and animal feed.
- **Local markets for maize are strong.** In total, Nigerian households directly purchase an estimated 2.5 million tons of maize grain each year to then process themselves or at fee-for-service mills.
- **Maize flour milling is a Tier 1 opportunity.** Most existing small-scale processers are millers who produce corn meals and flours. Most maize milling is already mechanized, and electric motors may replace the diesel prime movers in existing mills.
- **Mini-grid-run maize threshing may provide a revenue stream for developers.** Maize is typically mechanically threshed by businesses based outside mini-grid communities but customers show a willingness to utilize a local fee-for-service thresher in the community center.

A.3.1 Crop Background and Market Characteristics

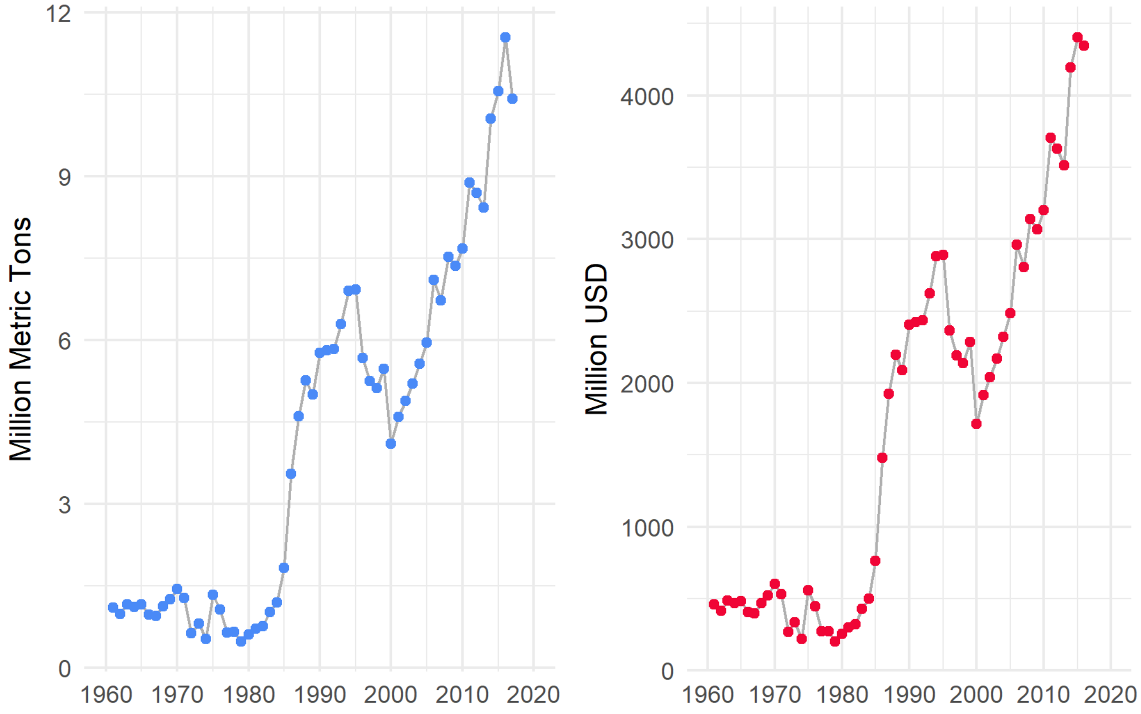
The Nigerian maize economy leads sub-Saharan Africa in gross production (10 million metric tons), number of farmers (9 million households), and land area (5.7 million hectares).[27] Maize offtake markets are split roughly evenly between human consumption and animal feed.[28] Households use maize meal for many traditional dishes including *pap, tuwo, gwate, donkunu, massam,* and *guraza.* 20% of Nigerian households consume these maize-derived products at least once per week, each of which requires maize to be ground into flour meal.[29] In total, Nigerian households directly purchase an estimated 2.5 million tons of maize grain each year to then process themselves or at fee-for-service mills.[27]

Roughly 15% of domestic maize is processed into consumer food products such as cereal or beer. The processed animal feed market consumes 50–60% of domestic maize production, with poultry and aquaculture feed driving demand increases over time.[27] As local incomes increase, so does demand for chicken, fish, and eggs, and thus the maize feed markets have shown strong correlation with Nigerian economic growth.[9] From 2003 to 2015, the volume of feed used in Nigeria increased 600%, largely driven by investment in poultry feed.[30] Maize is by far the greatest contributor to animal feed in Nigeria, with sorghum, cassava and wheat as distant runners-up.[28]

Suleiman Usman farms maize and soybean in Makaurata, Kaduna State. He harvests about 3 tons of maize per year and stores them near his home. Around 200 kg (7%) are lost to spoilage each season.

Maize was the most widespread crop across the two states studied, cultivated in 70% and 100% of communities in Cross River and Kaduna states, respectively. Maize can thrive under the high solar radiation and seasonal rainfall that characterize Nigeria's middle belt.[31] However, Nigerian farmers lag other African producers in yield: averaging just 2 t/ha versus 3.8 t/ha average in South Africa and potential yields of nearly 5 t/ha.[10,32] These lower yields have been largely attributed to inadequate soil nutrient management and water supply shortages in drought years, though experts warn that over-application of fertilizers in response to these challenges could endanger soil and water resources in the long term. [33,34] Though all maize farmers surveyed stated interest in expanding their maize production to increase dry grain sales, other studies find that market conditions do not incentivize farmers to intensify production through investing in their farms, as low grain prices and high transport costs limit profit margins.[35] As with several other crops in this analysis, climate change poses an ongoing risk to maize farmers as erratic rainfall, floods and drought degrade soil fertility and crop output.[36] For now, Nigeria leads Africa in total production by keeping very large amounts of land under maize – 626,000 hectares are dedicated to maize in Kaduna state alone. [27]

Figure 23: Gross National Production (Left) and Farm-Gate Value (Right) of Nigerian Maize[10]



Nigerian maize production has grown steadily in volume and value since the 1980s despite interannual disruptions due to regional conflicts, pestilence and drought (**Figure 23**). Almost all production is consumed domestically, with less than 1% formally exported.[29] Imports play a limited role as domestic maize dominates local food retail volume in small towns and big cities alike.[37] Trade flows generally move dried maize grain from production zones in the central belt and northern states and towards feed processing centers in Ibadan, Lagos, Warri and Enugu in the south.[38] Some informal trade occurs across the border and into neighboring countries.

A.3.1.1 POST-HARVEST LOSSES

Most smallholder maize is dried on the stalk, harvested, sun-dried once more, threshed, and then sold as dry grain. Once properly dried, maize is relatively shelf-stable and can be stored for about three months with limited risk of spoilage.[17] However, improperly handled maize is at risk of spoilage. Offtakers report losses of 3–10% of maize grain at the local aggregator level due to improper storage and drying. [xxxiv] Likewise, 50% of maize marketers and 80% of maize feed millers report losses due to spoilage.[17]

[xxxiv] Interviews with Nestle Nigeria, Diageo, January 2020.

Aflatoxins are a primary source of contamination for stored maize grains. The toxins are byproducts from *Aspergillus* fungi that grow in grain with >14% moisture content that is stored in warm environments. Peanuts and other grains, like sorghum, can also be affected by aflatoxins.[39] The Standards Organization of Nigeria imposes limits on aflatoxins in packaged foods, although the strength of enforcement by the Nigerian Agency for Food and Drug Administration is perceived to be low.[40] Compared to industrially processed maize, locally produced food products are much more likely to be incompletely dried, improperly stored, and contaminated by aflatoxins. This is one important barrier to integration of local maize grains or maize products into industrial food markets.

Common ground-drying techniques exacerbate risk of aflatoxin accumulation, as does storage of grain at more than 14% moisture content, in humid environments that stimulate mold growth.[41] The solution to these losses is to store properly dried grain in improved bags or metal silos.[42] Access to improved storage is solvable with access to capital and extension services. However, as climate change continues to make seasonal rains less predictable, traditional sun-drying practices will become increasingly unreliable means for producing safe, dry maize grain. Low-cost mechanical grain drying may reduce post-harvest losses, but there are significant barriers to adoption in a mini-grid context (**Appendix A.3.3**).

Commercial field treatments such as Aflasafe have been developed to prevent growth of aflatoxin-producing fungal strains on crops at a cost of 12–20 USD/hectare, but these treatments have yet to be widely adopted in the areas we surveyed.[xxxv]

A.3.2 Value Chain Description

Nearly 100% of maize in Nigeria is harvested for dry grain. In this value chain, all maize is left in the field until partially dry, then de-husked, dried further, threshed and winnowed. 50–60% of this maize is then bagged and ultimately processed into animal feed. Of the maize production that goes to human food, nearly 100% is milled into a meal or flour before consumption. We observed mechanical maize flour mills in most maize-producing communities we surveyed. We present the value chain for maize flour here because it includes most local processing steps (**Figure 24**).[xxxvi]

Late-season maize drying in the field prior to shelling.

[xxxv] https://aflasafe.com/

[xxxvi] Photo by Daniel Schludi on Unsplash.

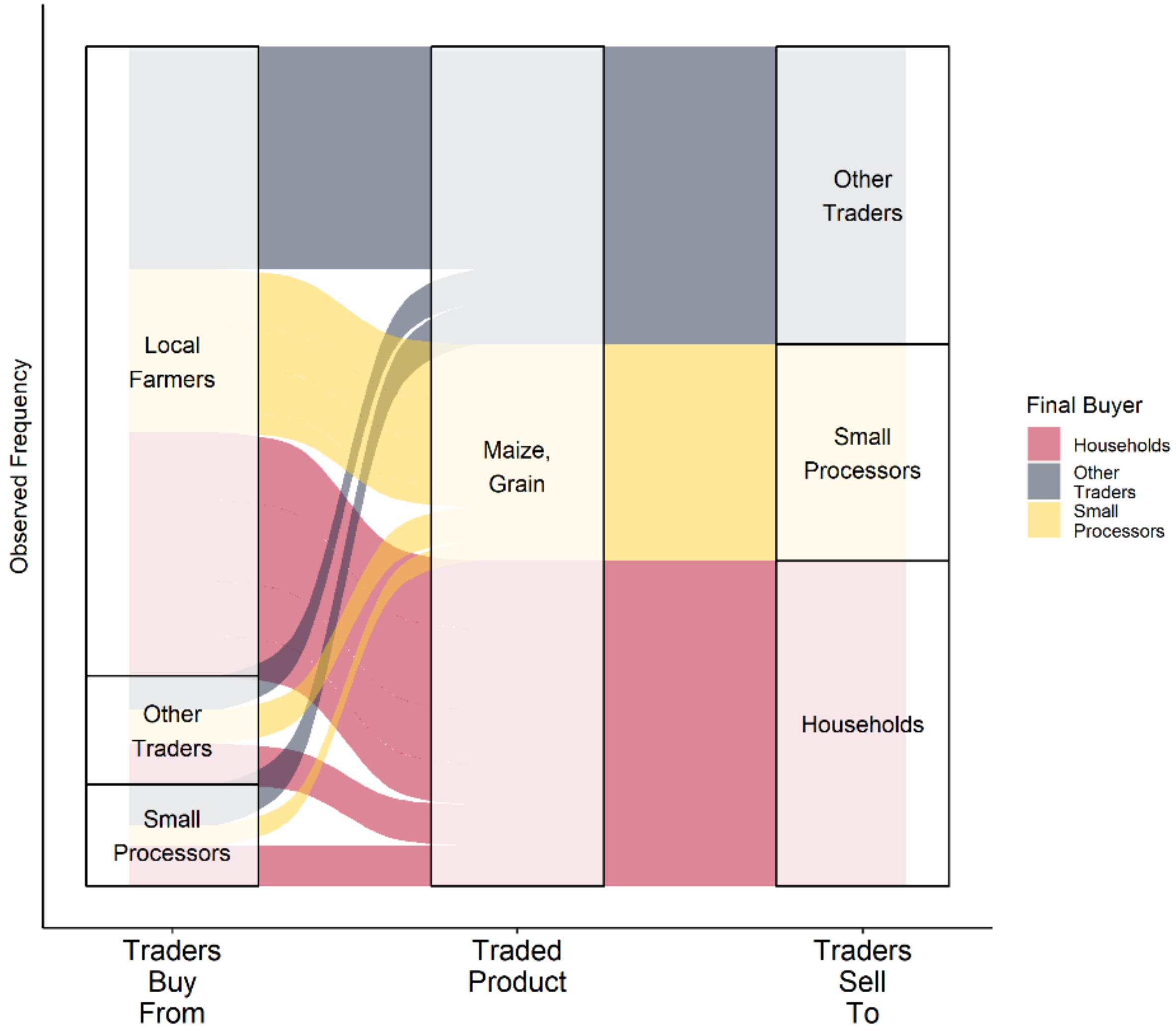
Figure 24: The Maize Value Chain from Harvested Cobs to Maize Flour

Description	*Mechanization*
Maize is partially dried on the stalk in the field, then de-husked.	Harvesting is typically manual.
Maize is typically sun-dried on the cob before shelling.	Grain dryers rare in smallholder context.
During shelling, dry maize grains are removed from the cob. Winnowing separates the chaff from the grain.	Fee-for-service mechanical maize shellers operate in larger towns and peri-urban communities. Some devices include a grain cleaning step.
An optional de-hulling step sometimes precedes milling to remove the bran layer.	Hulling is mechanized if performed, typically employing Engelberg hullers.
Clean, dry grains are milled into a meal or fine flour.	Fossil-powered plate or hammer mills are typically used.

A.3.2.1 LOCAL TRADE

In the mini-grid-suitable communities surveyed, maize was primarily traded as dried grain **(Figure 25).** Most local traders sourced from local farmers and sold to a mixture of local household and small processors. About one third of traders primarily sold this grain on to other traders beyond the community. These trade patterns are evidence of strong local markets for maize grain, including a large portion that is milled into flour by small processors, or by households at fee-for-service mills.

Figure 25: Local Trade Flows for Dried Maize Grain



Flow size is proportional to the likelihood of the trade from source to final buyer.

A.3.3 Opportunities for Electrification in Maize Flour Production

Analyzing key considerations for maize flour production activities finds Tier 1 (maize flour milling), Tier 2 (threshing and winnowing), and Tier 3 (mechanical grain drying) opportunities. These analyses are included below.

TIER 1

Maize Flour Milling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	●	Most maize-producing communities surveyed had at least one mechanized maize miller within the town.
Offtake Market	●	Maize meals are staples with strong local markets.
Electric Equipment	●	Electric maize mills are available in Nigeria, and old mills can be retrofit with new electric motors.[xxxvii] After a quality control pilot, these pieces of equipment are ready to deploy at scale.
Scalability	●	Maize has the broadest geographical coverage of the crops studied and local mills account for about a quarter of domestic processing.

Nearly all maize staples are made from a maize meal or flour, which is typically produced from a fossil-powered mill. In Nigeria, the textured, coarse flour of a plate mill is preferred to the fine powder of a hammer mill.[43] During flour, milling oversized petrol or diesel motors turn a mill drive shaft to perform the grinding motion of the equipment as shown in the image to the right. Processor interviews confirm that these mills tend to have high operation and upkeep costs, and the combustion motors that drive them are old, noisy, and unreliable.

A recent pilot by the Efficiency for Access Coalition introduced battery-coupled and plug-in electric maize mills to operators in Tanzania, Kenya, and Uganda.[5] Although the battery-coupled devices allowed the mill to function off-grid, operators and customers found the 33 kg/hour throughput to be far below the acceptable capacity, leading to long wait times for fee-for-service customers. To increase this capacity, manufacturers would need to increase PV and battery capacity, thus raising the equipment price. Unlike standalone solar setups, mini-grid-connected mills can draw on

Ishaq Haruna running his 22 horsepower diesel flour mill in Kadage, Kaduna state. Mr. Haruna spends $4.40 US per day on diesel to run his mill compared to an estimated $1.80 he'd spend on electricity from a mini-grid with a $0.60/kWh tariff.

[xxxvii] Bennie Agro (NG) sells an electric multipurpose miller with 2000 kg/hr capacity, powered by an 18.6kW three-phase motor, see **Appendix B**.

plentiful three-phase power to match diesel motor throughput. There are a range of electric models on the market today that claim 250 to 2000 kg/hour capacities with 3 to 18 kW induction motors.

Section 4 presents the business case for an electric multipurpose grain mill. Mill economics are further increased when the appliance can be utilized to process other commodities such as cowpea, sorghum, rice, and soybean[43]. As **Appendix C.3** shows, a 10-metric ton increase in annual volume translates to a $540 increase in net present value.

The only untested aspect of electric grain flour milling is the compatibility of specific electric mills with mini-grid hardware. As described in **Section 7** and **Appendix A.1.2**, pilot testing of specific mill models will be a necessary step to ensure customer satisfaction and smooth operation for both mini-grid and mill operator.

TIER 2

Maize Threshing

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◑	Mechanical threshing is common among maize farmers, though mobile mechanical threshers are often brought in from outside communities.
Offtake Market	●	Local traders, households, and processors provide a strong market within mini-grid-suitable communities.
Electric Equipment	◕	Electric maize threshers are available in Nigeria[xxxviii] and old threshers can be retrofit with new electric motors.
Scalability	●	Nearly all maize grain is shelled from the cob before sale or processing, and all maize farmers report interest in a mechanical threshing option for the right price.

Manual maize threshing (also called "shelling") is a very slow process, at most processing 25 kg of maize grain per person per hour.[44] As a result, nearly 90% of maize farmers pay to speed things up either by hiring manual labor or a mechanical thresher. Of the crops targeted by this study, maize was most likely to be mechanically threshed, with only 30% of farmers reporting that they predominately utilized manual threshing (**Figure 18**).

However, there were no local threshing machines reported to be located within the mini-grid-suitable communities surveyed. During harvest season, local entrepreneurs travel between communities to offer mobile threshing services to remote farmers, as shown in the photo below. An electrified version of this mobile business model would require a battery-powered threshing system, which has not been developed to date. However, plug-in electric threshers are available in Nigeria and could be centrally located in mini-grid powered communities. This centralized threshing model would require harvested crops to be transported from the farm to a stationary machine, which poses a transportation problem for many. Survey enumerators observed that some farmer cooperatives are bridging the infrastructure gap between rural communities and centralized threshing sites by collecting the produce in rural communities and transporting it back to centralized threshing sites.

If the transportation problem could be solved, 87% of interviewed maize farmers said they would be willing to transport their maize harvest to a central threshing area. However, customer willingness to pay for

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[xxxviii] Unic and sons (NG) sells a mechanical thresher with 400kg/hr capacity, powered by a 1.8kW single-phase motor while Bennie Agro (NG) sells a mechanical thresher with 2000kg/hr capacity, powered by 14KW three-phase motor.

this service, after accounting for transport costs, is unknown. Comments from field enumerators indicate that even if mechanical threshing is available, farmers will typically choose the cheaper of the two options between manual and mechanical threshing. In addition, the seasonality of the maize harvest and interannual fluctuations in production make it difficult to anticipate the capacity utilization of this equipment over its life.

Mini-grid threshing pilots can further test the business model for stationary electric maize threshers, to ensure customers are willing to pay fees that can justify the cost of owning and operating the equipment. Mini-grids that own and operate threshers may be able to use excess peak solar power to keep operating costs close to zero, improving the likelihood that customers can be served at a reasonable fee.

Nonetheless, success requires either development of a battery-powered appliance or additional due diligence to ensure off-grid uptake of a centralized threshing model. Thus, we classify this activity as Tier 2.

A petrol maize thresher operating in a peri-urban zone outside Abuja.

TIER 3

Mechanical Maize Grain Drying

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Nearly all maize grain is sun-dried. Introduction of a mechanical option would require capacity building.
Offtake Market	◑	Offtakers may offer higher prices for improved grain quality with uniform moisture content, but only through aggregators who can ensure scale and quality.
Electric Equipment	◔	Mechanical grain dryers commonly use fossil fuel as a heat source. All-electric options are available in Nigeria but will likely be cost-prohibitive to run at mini-grid electricity prices.[xxxix]
Scalability	◕	All maize grain is dried: an appropriate drying technology combined with a market to value precise moisture content control could achieve scale.

As described above, maize grain suffers from aflatoxin contamination primarily because of prevalent sun-drying techniques that expose the grain to contaminants and fail to reduce the moisture content below 14% before storage. Industrial offtakers acknowledge this problem and have expressed interest in paying

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[xxxix] Some members of the Agricultural Machineries & Equipment Fabricator Association of Nigeria (AMEFAN) sell electric dryers.

premiums for quality, dry grain if an aggregator could conduct the transaction at a large scale. However, the exact price increase that a farmer or entrepreneur would experience is dependent upon the negotiated contract price between the aggregator and offtaker, and it is unclear whether the operating costs of local mechanical drying can be sustained by the marginal price increase of selling premium quality grain.

One third of maize farmers interviewed experienced difficulties in sun-drying maize at least once per season, and it is likely that many more are failing to dry to safe moisture levels without detecting the problem.[40] However, mechanical drying practices remain untested in mini-grid-suitable communities and it is unclear that provision of mini-grid electricity will improve the prospects of the practice. Crop dryers in developed contexts typically use natural gas, liquefied petroleum, or biomass fuel as a heat source, as resistive electrical heating is cost prohibitive. Solar dryers or hybrid solar-fossil dryers utilize solar radiation to heat their contents directly, thus reducing fuel costs.[45] Others utilize ultrasound, infrared and/or micro electromagnetic waves to dry crops using electricity, and at a higher degree of energy efficiency.[46] These alternatives to conventional drying are better suited to electrification. However, our review of appliances available in Nigeria did not find models of these low-energy alternatives, and it's likely that further equipment and market development would be required to prove and scale the technologies. Despite all the appliance options, a corrugated metal roof and concrete slab may provide the simplest, cheapest boost to sun-drying.

Maize drying prior to shelling in Takalafiya community, Kaduna state after an October harvest.

A.4 *Rice*

- **Domestic rice production and processing is smallholder-led, substantial and growing.** Consumer preferences, government policies, and agricultural development efforts provide strong tailwinds for Nigerian rice.
- **Domestic rice struggles to beat imports on quality and price.** Imported rice is cheaper, higher quality and typically delivered directly to population centers.
- **Rice milling is a top opportunity for electrification.** 80% of Nigerian rice is processed by small-scale millers, most of whom operate outdated equipment. Replacing old one-stage diesel rice mills with new two-stage electric mills can reduce process losses and operating costs and improve quality by better separating by-products and reducing breakage
- **Wood-fired parboilers are prevalent, smoky, and predominantly operated by women, but difficult to electrify.** Though there is much room to improve parboiling efficiency and reduce indoor air pollution impacts, it is unlikely that mini-grid electricity could cost-effectively serve the need.
- **Irrigation is necessary for optimal yields but unlikely to be electrified by mini-grids.** Today, rice fields – and the irrigation pumps that serve them – are located far from community centers. For electric irrigation pumps to be profitable to serve, the cost of building distribution to the rice fields must be balanced by electricity sales to pumps that are not run continuously throughout the year.

A.4.1 Crop Background and Market Characteristics

Rice is the third most valuable Nigerian crop after cassava and maize, with an annual market value around $3 billion per year.[10] Nigerians consume an average 32 kg of rice per capita per year, which translates to roughly 1% of 2019 per-capita gross domestic product.[47] The share of rice in the Nigerian diet has increased by 12x since the 1970s, and demand for rice is expected to continue as customers substitute rice for traditional staples that are more time-intensive to cook.[48] Smallholder farmers account for 80% of Nigerian rice production.[49] Rice was reported to be cultivated by five or more farmers in 75% and 46% of communities surveyed in Cross River and Kaduna states, respectively.

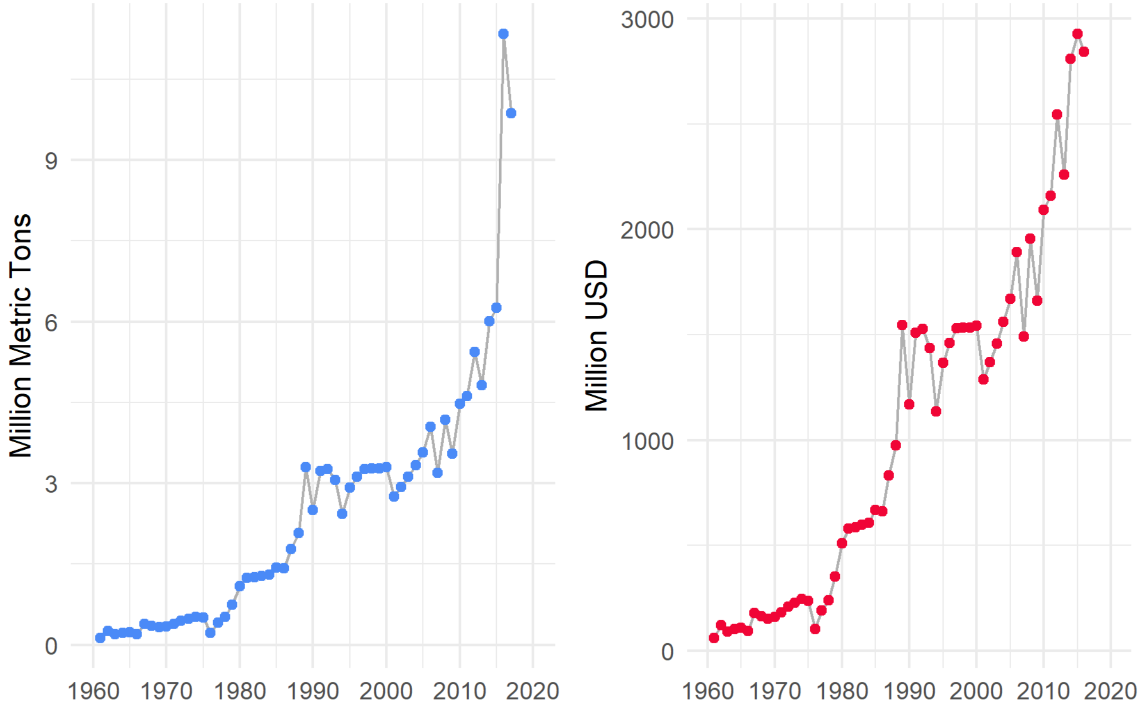
Despite sizeable domestic production, Nigeria is consistently among the world's top three rice importers. Consumers prefer cheaper imports from Thailand and India: in some markets roughly five bags of imported rice are sold for every bag of local rice.[28] Imports are also driven by growing customer appetites for polished, contaminant-free, high-quality rice.[50] The Nigerian government has attempted to impose a 70% tariff on rice imports arriving by sea and in 2019 imposed an outright ban on all overland trade.[28] Under these policies, some foreign rice still enters Nigeria illegally by way of neighboring countries with lower import tariffs and permeable borders but several sector stakeholders report an uptake in demand for local rice in response to the border closings.[51]

A woman winnowing threshed paddy rice by hand near FCT in Nigeria.

The poor competitiveness of domestic rice production is driven largely by low ability to pay for mechanization and inputs in primary production: the national average mechanization rate is estimated at 0.3 hp/ha, compared to an FAO-recommended minimum of 1.5 hp/ha.[52]

Nigerian rice yields are just 50% of the global average.[10] This is due to a variety of factors including high transportation costs and lack of access to improved seeds, fertilizer, and irrigation.[53] Rice grains are the seeds of a grass plant that flourishes under irrigated conditions. Since most Nigerian rice is produced by smallholder farmers, good crop yields require disparate smallholders to seasonally irrigate their paddies. Access to irrigation depends on a variety of factors across Nigeria's agroecological zones, but only 15% of rice-growing area is estimated to be irrigated nationally.[28,54] Small-scale irrigation could double rice yields under certain conditions, though the financial benefit to farmers will depend on irrigation cost, the fertilizer application rate, and farmers' risk tolerance.[55] In addition, the farmers we surveyed report that their fields are typically far from the town center: 92% say it takes longer than 15 minutes to walk there, and 25% report a commute longer than 45 minutes. Assuming a 4 mile-per-hour walking speed, this puts average farms more than a mile from the city center, which is beyond the service territory for most mini-grids. For more discussion of the limited role of mini-grids in irrigation, see **Appendix A.1.3**.

Figure 26: Gross National Production (Left) and Farm-Gate Value (Right) of Nigerian Paddy Rice[10]



A.4.1.1 POST-HARVEST LOSSES

Post-harvest losses in Nigerian rice may be as high as 20–40%.[56] Losses typically occur through harvest, processing, and market stages, with minimal spoilage occurring at the consumer level.[57] Storage losses are not a major concern. Losses due to spillage from containers and mishandling during the marketing process cannot be resolved through modern, electrified equipment. However, traditional threshing, and parboiling processes each lose about 5–6% of incoming paddy rice. At the milling stage, traditional mills also waste paddy components by failing to adequately separate waste streams from milled paddy and from each other, as discussed below.

A.4.2 Value Chain Description

Figure 27 shows the rice value chain from harvest to milled head rice, focusing on parboiled rice production which represents over 90% of the local rice consumed in mini-grid communities in Nigeria.

Figure 27: Rice Value Chain from Harvested Rice Plants to Milled Head Rice

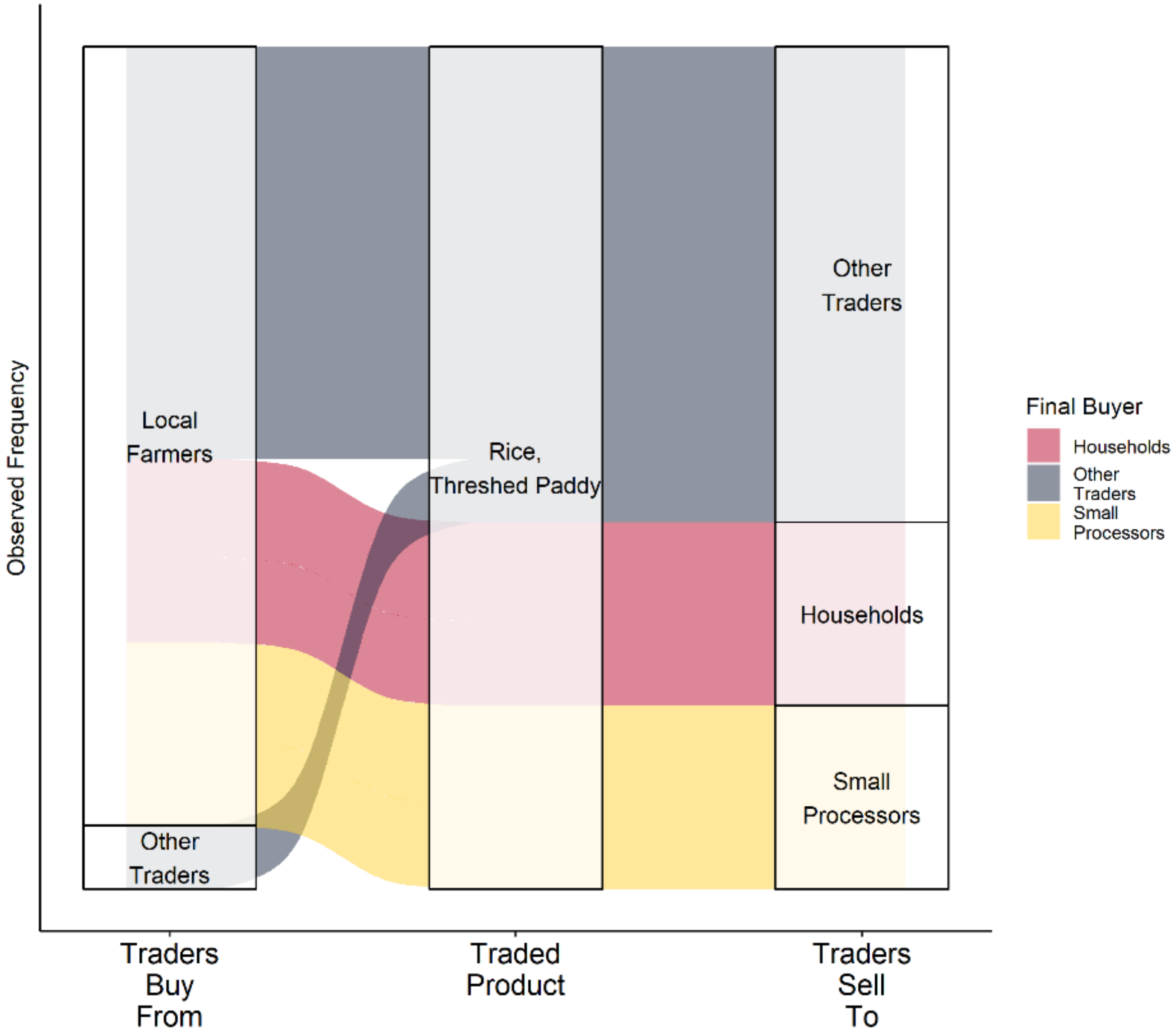
	Description	Mechanization
Thresh	After drying in bundles in the field, rice grains are removed from the plant by threshing. This activity occurs at the farm site.	Typically rice is threshed hitting the plant on a hard surface, which damages grain and introduces contaminants. Mobile mechanical threshers improve quality and yield.
Dry & Winnow	Rice is dried to ~14% moisture content on drying floor or tarpaulins. Winnowing removes light chaff material from grains but does not separate heavy debris.	Nearly always sun-dried. Mechanical dryers of various kinds exist but are not employed in Nigeria. Winnowing is performed by tossing paddy rice into the air.
Parboil + Dry	Partial boiling involves soaking rice at 60-70 C for 8 hours, steaming for 10-20 minutes, and then re-drying. Parboiling improves nutrition and milling yields. Exclusively women-led.	Standard practice is to heat a 42-gallon oil drum with a wood fire. A variety of efficient parboilers still use wood but make better use of heating fuel.
Mill	Milling removes the rice husk and bran to produce a polished grain. Milling is male-dominated.	Milling is 100% mechanized. Most small mills are old single-stage diesel machines. New electric two-stage mills improve head rice recovery and better separate the byproducts from polished rice.
Destone	An optional cleaning step can remove debris introduced upstream in the value chain. Both paddy and milled rice can be cleaned.	Destoning can be done by hand using sorting trays. Modern rice mills often have an attached destoning unit.

A.4.2.1 LOCAL TRADE

Local rice traders predominantly source threshed paddy rice from local farmers **(Figure 28).** Half of local traders report that they sell primarily to other traders outside the community, with the other half staying among local households and small processors. The portion of the rice that stays within the community will typically be parboiled and milled by local entrepreneurs and households. These trade flows are evidence of very strong local offtake markets for rice milled in mini-grid communities.

Figure 28: Local Trade Flows for Paddy Rice

Flow size is proportional to the likelihood of the trade from source to final buyer.



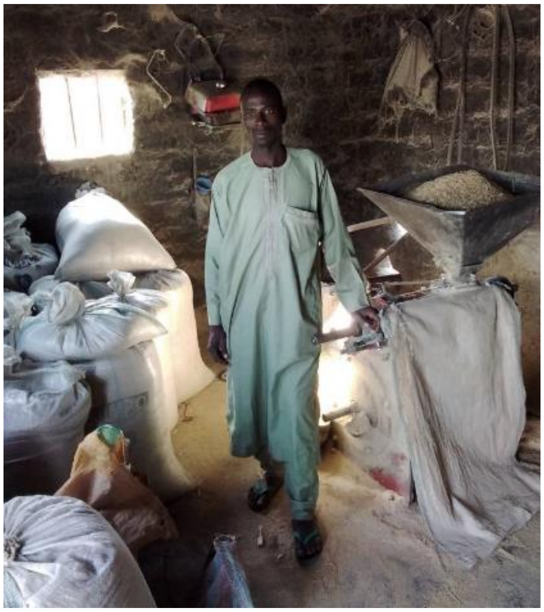
A.4.3 *Opportunities for Electrification in Rice Milling*

Analyzing key considerations for milled rice production activities finds Tier 1 (rice milling) and Tier 3 (threshing, mechanical grain drying) opportunities. These analyses are included below.

TIER I

Rice Milling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	●	Local rice mills were observed in 100% of the rice-producing, mini-grid-suitable communities surveyed.
Offtake Market	●	Strong demand for locally milled rice by households and markets.
Electric Equipment	●	Electric rice mills are available, and two-stage rice mills[xl] offer strong value proposition over outdated one-stage mills.
Scalability	●	80% of domestic rice is milled by small-scale local processors.



Habibu Lawal with his 25 hp diesel one-stage rice mill in Zagezagi community, Kaduna state. Habibu reports spending N4600 on diesel alone during a busy day of milling, and an addition N5000 per month for maintenance of the aging motor. This mill yields 50 kg of milled rice for every 100 kg bag of paddy rice. New mills can improve quality and boost milling yields by 20–30%.

Rice milling is a top-tier opportunity for electrification with mini-grids, and there's strong national demand for the service. **An estimated 80% of domestic rice consumed in Nigeria is milled at the local level by processors with <500 kg/hour milling capacity.**[58] These smaller mills cannot serve the market demand: circa 2014, the annual demand for milled rice was 1.9 million tons greater than annual production.[56] At the same time, an estimated 80% of industrial rice mills are running at less than 25% capacity as they struggle to source sufficient local rice to sustain their operations.[59] Local small-scale rice mills have ready access to paddy rice produced nearby, pushing their capacity utilization up to 50%.[60] But smaller players struggle to reduce operational costs enough to compete with imports on price.[28]

Most small rice mills operating in Nigeria today are old, expensive to run, and produce a low rice yield at suboptimal quality. One study found that the average age of rice mills in operation to be 18 years.[61] Most of these old mills are single-pass one-stage 'Engelberg' rice mills that produce a basic milled rice and a mixed waste residue that contains broken grain, rice bran, and rice husks. Modern two-stage mills reduce grain breakage and better separate these byproducts, resulting in better quality milled rice. High quality rice grains can be sold at a 50% price premium (170 N/kg vs 115 N/kg).[56] The separation of rice bran and rice husk allows processors to sell these waste streams as an animal feed input or a biomass fuel for parboiling, respectively.[56]

Energy costs are 65–80% of operating costs for fee-for-service rice mills, and it is estimated that a 1% increase in diesel price can drive a 10% increase in cost of production over the lifetime of the mill.[61]

[xl] NCAM (NG) sells a two-stage rice mill with 800kg/hr capacity, powered by 10.4KW three-phase motor, see **Appendix B.**

Efficient, three-phase electric motors can vastly reduce millers' exposure to fuel price risk. **Appendix C.4** presents the rice milling business case in further detail.

TIER 3

Rice Threshing

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Rice is typically threshed manually in mini-grid-suitable communities. If a fossil-powered mechanical thresher is used, it operates where the harvest occurs: in fields that may be far from community centers.
Offtake Market	●	Strong demand for paddy rice by local households, processors, and traders.
Electric Equipment	◑	Electric rice threshers are available but would need to be situated in a central area to be powered by a mini-grid, requiring actors to change their practices.[xli] Standalone solar or battery-powered threshers could enable mobility but have yet to be developed.
Scalability	●	Threshing is a critical step in all rice harvests in Nigeria, and the task must be done at the local level. Demand for a **cost-competitive** mechanical threshing option would be widespread.

Threshing removes the dense rice grains from the bulky grass on which it grows. This step increases the density of the material and enables efficient transport and handling throughout the rest of the value chain. Therefore, rice value chain actors strongly prefer early threshing at the farm site over transportation of the crop to a centralized threshing location. Mechanical rice threshers are typically mobile equipment that can be easily transported by light vehicle or by hand. An added benefit of in-field threshing is that it allows the excess rice plant material to be returned to the soil, which helps prevent depletion of soil carbon.[62] These mobile threshers have proven to be good investments, achieving an estimated 50% IRR.[57]

Electrification of rice threshing would require either 1) a change in value chain practices to transport rice to centralized threshing locations, or 2) development of a mobile electric rice thresher. Because transporting whole rice plants is suboptimal, as discussed above, a grid-independent thresher is the most likely solution. If a mini-grid is present, a battery system could be paired with an existing thresher design, although further investigation would be required to determine if the power and size requirements of this power supply can be met at a price point that does not render the battery thresher uncompetitive with fossil options.

During manual threshing, an estimated 5% of rice is broken or scattered on the ground as the grains are beat from the grass. Additionally, manual threshing practices are more likely to introduce stones and other small debris into the paddy, raising the non-rice content (i.e., "add mixture"), and lowering the sale price. Compared to manual threshing, mechanical threshers increase output capacity from roughly 30 to 150 kg/hour.[60] Taken together, electrical threshing stands to be 5x faster while reducing post-harvest losses and slightly increasing the sale price.

If the correct device can be designed and successfully piloted, there is likely to be a strong offtake market and high potential for scale across the country. Nearly all rice farmers report that they would be interested in utilizing mechanical threshing if it is cost-competitive with hiring laborers for manual processing (**Appendix A.1.1**). But only 18% report that they would "definitely be willing" to transport their

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[xli] Alaral Tech Engineering Design & Fabrication, member of AMEFAN sells electric rice threshers, see **Appendix B**.

harvested rice to a centralized threshing location served by a mini-grid. For the rest, the success of mechanized threshing depends on the price of the service as well as its ability to accommodate the preferences and habits of value chain actors.

Rice Parboiling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◑	Locally milled rice is parboiled in mini-grid-suitable communities, typically using a pot or oil drum heated over a wood fire. Operation of more efficient parboiling vessels would require capacity building to change practices.
Offtake Market	●	Strong demand for parboiled rice by local households, processors and traders.
Electric Equipment	◔	There are no electric parboilers on the market. In theory, a very energy-efficient electric parboiling vessel may be cost-competitive with wood at mini-grid, but such a device has yet to be designed.
Scalability	●	Parboiling is a critical step for domestic Nigerian rice and is typically done at the local level.

Parboiling gelatinizes the starch in paddy rice grains which toughens them and reduces breakage during milling.[63] It also moves nutrients from the bran (which is removed during milling) into the inner portion of the grain, improving nutrition of the otherwise starch-heavy grain that remains after milling.[64] Finally, parboiled rice is simply easier to cook. Because of these benefits and consumer taste preferences, 90–95% of Nigerian paddy rice is parboiled.[57]

The parboiling process varies according to consumer tastes and traditions, but typically entails 4–8 hours of soaking in hot water (initially 60–70° C), followed by 10–20 minutes of steaming (100–110° C).[65] During steaming, some quantity of water is heated to a boil in the pot and the rice is added directly into the boiling water to partially cook. After parboiling, the paddy rice is air-dried, ideally to the ~14% moisture content preferred by millers.

Traditional Parboiling Practices

Traditional parboiling techniques are time-consuming, energy inefficient, and inconsistent in quality. Most parboilers use open pots or oil drums heated by wood fires, as shown to the right. These heating systems are inefficient, imparting heat from the firewood to the surroundings as well as to the pot contents. Hard-earned heat also escapes as steam through the top of the lidless container rather than staying in the parboiling rice mixture. These inefficiencies mean that traditional parboilers are using around **seven times** more energy than required, which translates to extra fuelwood and longer periods of time spent tending smoky fires.[66]

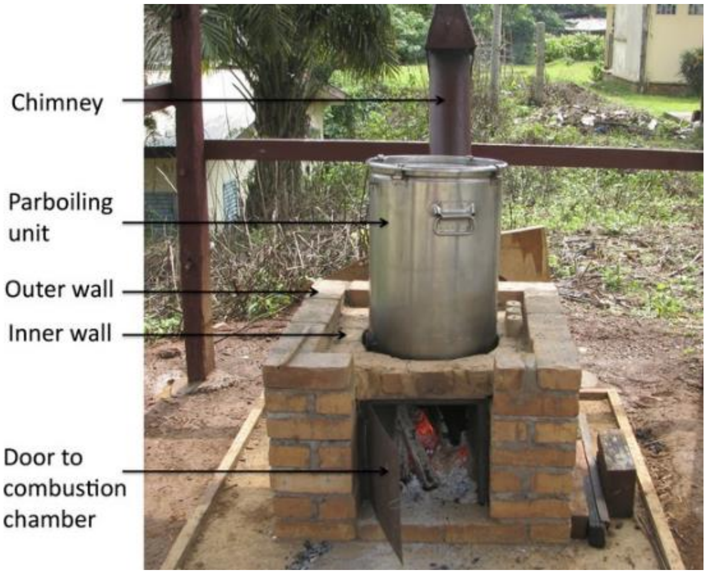
Women bear the burden of the parboiling process, including the time requirement and long-term health hazards of smoke inhalation.[53] 100% of the participants asked about the gender balance of parboiling reported that the activity was always performed by women.

A traditional parboiling arrangement in Dawan Malam community, Kaduna state.

Improved Parboiling Practices

These problems have made parboiling a strong target for development intervention. Interventions have introduced of a variety of improved parboiling vessels, as well as capacity building programs. The RIPMAPP program introduced simple false-bottom pots that heat only the minimum amount of water required for steaming, and use a lid to contain the steam within the pot.[67] This configuration reduces energy requirements and evenly steams the rice as the steam equally heats each grain throughout the pot, which reduces inconsistencies in quality in the batch. In 2018, RIPMAPP reported a 10–20% price improvement due to adoption of these improved practices by over 14,000 parboilers. AfricaRice's larger GEM Parboiler utilizes a pot with a specialized steaming basket to ensure even heating and an improved wood stove to improve heat transfer from the fire to the parboiler contents (see image).[68] In both cases, significant capacity building was required to ensure proper operation of these improved parboiling methods.

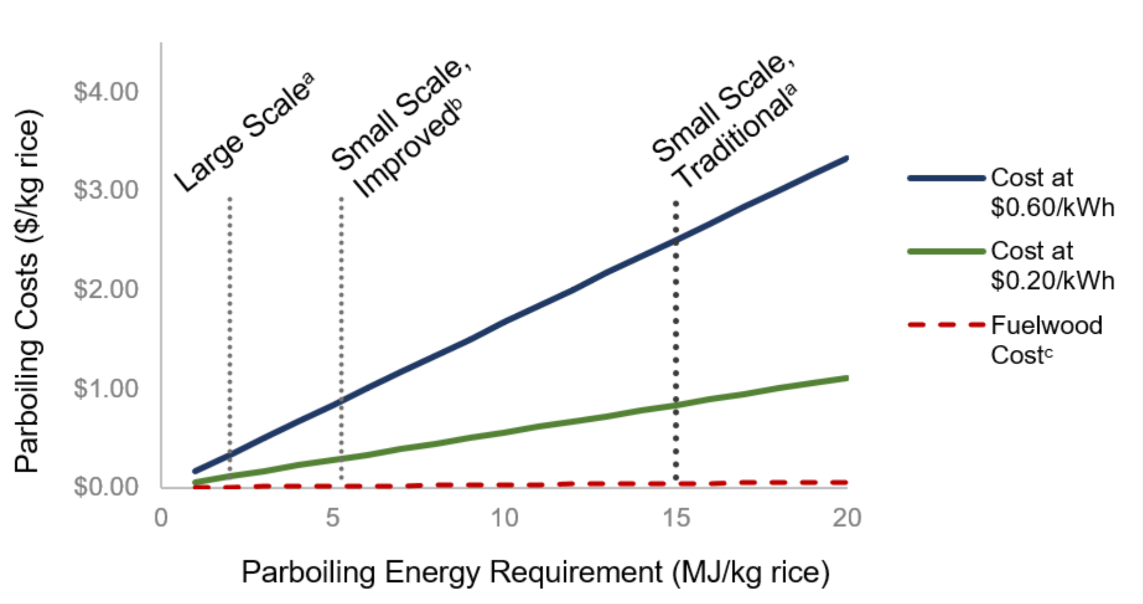
In addition to improving energy efficiency, parboiling operations may be improved by using alternative heat sources. Simply burning rice husk waste from nearby mills may reduce the time and money spent on wood fuel by up to 35%, one study finds.[66] Purpose-built rice husk stoves may further improve combustion efficiency and reduce energy costs but are not mass produced.[69] Other agricultural residues such as maize stalks were occasionally used as a wood substitute by our survey respondents. **Mini-grid electricity could in theory serve parboiling heat demand, but in practice this is unlikely to be economically infeasible without significant improvement in energy efficiency and purpose-built electric heating parboilers. Box A.4** analyzes the cost of electrifying parboiling under various efficiency scenarios, showing that today's mini-grid tariff fails to compete with fuelwood heating on cost even given a 15-fold improvement in energy efficiency.



AfricaRice's GEM parboiling unit for medium-scale operations. Photo excerpted from Ndindeng et al., 2015.

Box A.4: Electrification of rice parboiling is not cost competitive with fuelwood even if significant efficiency improvements and mini-grid tariff reductions are achieved.

Figure 29: Cost of parboiling one kilogram of paddy rice using different energy sources, at varying levels of energy efficiency. References: [a] Kwofie, 2017; [b] Ndindeng, 2015; [c] Usman, 2014.



Today in Nigeria, it is much cheaper to parboil with wood than with electricity. The above plot shows the costs of parboiling one kilogram of paddy rice using fuelwood and using electricity at two different mini-grid tariffs. Dotted vertical lines demarcate the energy requirements (in MJ/kg rice) of three different operations: a large-scale commercial parboiler in India, a small-scale GEM parboiler developed by AfricaRice, and small-scale traditional parboiler. For reference, consider that one kilogram of milled rice is worth roughly $0.70-1.00 in local markets.

At $0.60/kWh – a mini-grid tariff reflective of today's prices – even industrial efficiencies do not reduce the parboiling energy costs below $0.20/kg. At $0.20/kWh – an aspirational tariff for the mini-grid sector – it's possible for *highly efficient* operations to approach $0.5-0.10/kg for parboiling energy expenditure. But such efficiency improvements will require purpose-built electric parboiling vessels, likely using induction heating and well-insulated container walls.

For the foreseeable future, direct fire heating of parboiling vessels will continue to be the norm in Nigeria. Moving away from wood fires may pose benefits to the local women who tend them, and who gather the wood. For these reasons, electricity may not need to reach precise cost parity with traditional practices. But such a transition will require significant electricity cost reductions, efficiency improvements, and local capacity building, all of which are beyond the scope of early productive use interventions by the mini-grid sector.

Mechanical Rice Drying

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Nigerian smallholders typically sun-dry grains, including rice.
Offtake Market	◑	Though mechanically dried rice can certainly be sold into existing local markets, these buyers may not value the improved quality due to lack of consistent grading standards.
Electric Equipment	◔	Some mechanical dryers are manufactured in-country but rely on fossil fuels as primary heat input.
Scalability	◕	All harvested rice must be dried before sale. If widespread quality standards increase the sensitivity of the market to rice moisture content, the scale of the activity is potentially large.

Before reaching the local market Nigerian parboiled rice is dried twice: first after threshing and then following parboiling. The target moisture content is 12.5–14% by mass.[67] Paddy rice stored with a higher moisture content risks molding during storage or reduced milling yields.

Most Nigerians sun-dry rice in the open air, and all survey respondents in the rice value chain used this method at least some of the time. Possible drying surfaces included bare ground, tarpaulins, roads, roofs, and purpose-built concrete platforms. These practices are typically adequate: only one in four rice farmers surveyed experienced drying problems during the busy season. However, many cereal grain stakeholders we interviewed predicted that climate change will make seasonal rains less predictable, and thus increase the proportion of farmers who are having trouble drying their crops. Additionally, sun-drying often introduces debris into the drying product.

The Standards Organization of Nigeria has specified a grading standards for paddy rice, and a variety of international milled rice standards are available.[70] Despite the existence of these standards, most smallholder rice is not consistently graded for quality at the paddy or milled rice stage. As a result, precise incremental improvements in dryness or quality are not consistently valued by local markets.

Mechanical dryers exist and are prominent in more developed markets with stricter tolerances for rice dryness and quality. These include some rice dryers that require input air to be heated (usually by fossil fuels), and other low-temperature units that require much less energy input.[71] Introduction of the latter may allow drying of rice using mini-grid power without reliance on other energy sources, but implementation of such an intervention would require significant capacity building. Other alternative grain dryers are discussed in our review of the opportunity for mechanical maize drying in **Appendix A.3.3.**

Although there are drawbacks to sun-drying of rice, many NGO-led efforts to introduce mechanical drying at the smallholder have failed.[53] Simply sun-drying on a raised concrete surface rather than the ground or a tarpaulin may significantly improve results, and plastic greenhouse-style solar dryers offer more control at zero energy cost.[72,73]

A.5 *Aquaculture*

- **Aquaculture provides food and livelihoods for millions of Nigerians.** Catfish account for 70% of fish farm production, while tilapia comprise an additional 10%.
- **Fish farm production falls short of meeting domestic demand.** Though aquaculture has grown rapidly in the past 20 years, significant market opportunity remains untapped.
- **Water pumping and aeration are cost-competitive to operate with mini-grid electricity, saving 25% of operating costs compared to diesel pumps.** However, the prevalence of ground-sourced water pumping is dependent upon the local watershed, and aerated aquaculture is not yet common in mini-grid-suitable communities.
- **Consumer preferences for fresh fish limit the viability of cold storage for aquaculture species today.** In local markets, catfish are sold live or freshly harvested to consumers, and the remainder is smoked. Refrigeration and freezing have more potential near natural fisheries, where freshly caught fish must often be preserved before sale in markets some distance from the point of capture.
- **Very little or no mechanization is involved in other aspects of fish processing in rural areas.**

A.5.1 Crop Background and Market Characteristics

Nigeria boasts the largest aquaculture production in sub-Saharan Africa, the second largest in Africa behind Egypt.[54] Nigerians spend about 10% of their food expenditure on fish, which accounts for over 50% of animal protein.[74] The aquaculture industry supports millions of people directly and indirectly and is particularly important at household and community level, contributing to livelihood, employment and household food.[75] Fish farming is not widely prevalent in the 41 mini-grid-suitable communities we surveyed: 0% of communities in Kaduna and 6% of communities in Cross River reported the presence of aquaculture. Other communities, regions, or states may have a heavier emphasis on this value chain.

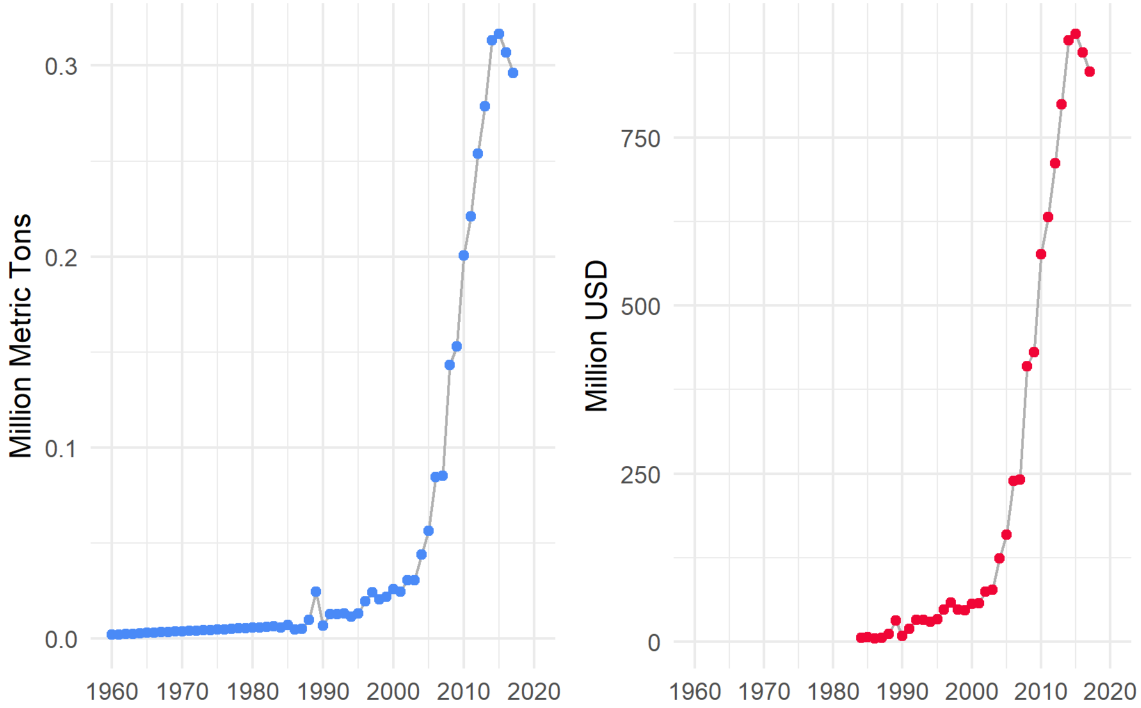
About 80% of Nigerian fish farms are small household and small-scale commercial farms producing on the order of 100 kilogram of fish per month.[75] According to FAO data, about 70% of these farmed fish are catfish, 10% are tilapia and the remainder is subdivided over dozens of other species.[54]

There is strong preference for fresh local fish, which features in traditional mainstays like catfish pepper soup. Farmed catfish can sell at twice as much as frozen fish.[76] This price differential is in part because rural fresh fish value chains are extremely localized, and often don't compete directly with frozen fish in larger supermarkets. More importantly, today most Nigerian consumers have a strong taste preference for fresh

Blessing Friday Ube preparing fish for sale in Atimbo, a peri-urban community 20 minutes from Calabar in Cross River state. She trades fresh catfish in addition to other captured fish from a nearby river, and reports that she would use refrigeration to store some of her products.

catfish and are loath to freeze or refrigerate them.[xlii] Thus, fish smoking is the most common ways to preserve farmed fish that has been harvested but fail to be sold fresh. Nigerians practice "hot smoking", in which the fish is cooked, smoked and dried by the process.

Figure 30: Gross National Production (Left) and Farm-Gate Value (Right) of Nigerian Aquaculture[77]



For the past 35 years, gross Nigerian aquaculture production has grown an average of **12% per year.**[78] However, during the same time period Nigerian fish demand has also grown as the country became more populous and wealthy. Today Nigeria is decidedly a fish importer: 2014 fish demand was 3.52 million metric tons, versus approximately 300,000 metric tons of aquaculture production and 700,000 metric tons harvested from natural fisheries.[54] As with most sectors with such strong trade deficits, the Nigerian government is keen to encourage further investment in aquaculture to reduce reliance on imports.

A.5.1.1 POST-HARVEST LOSSES

Post-harvest fish spoilage is limited as many farmers sell at farm gate and have the option to preserve leftovers through smoking and drying either themselves or through processors. Catfish is resilient and can survive a few days after harvest in a small tank or tub if the water is changed regularly. If stored too long, there is a risk of fish losing weight as they stop feeding while acclimating to new environments. From limited survey results, one fish farmer reported spoilage of around 5% and traders reported a range from 0–6% spoilage in their possession. Fish smoking is an effective practice for preserving the fish that does not sell fresh, keeping post-harvest losses relatively low.

A.5.2 Value Chain Description

In simplest terms, a fish farmer's job is to stock a pond with small fish and to supply those fish with feed and healthy water until a target weight has been reached (4–6 months).[79] Building this facility requires some upfront capital to construct ponds and procure pumps, but operating costs far outweigh capital expenses. A review of the literature finds that 85–97% of total cost of fish production was spent on

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[xlii] Interviews with PIND, Sahel Consulting, November 2019.

fingerlings, feed, labor, and fresh water.[80,81] All aquaculturists interviewed in this study reported that they purchased their fish feed from outside the community.

Healthy fish require healthy water. While fish are growing in production ponds, unhygienic environments and poor water quality can lead to high mortality rate (10% on average, up to 40% in some cases).[75,79] Water quality entails dozens of factors and smallholder fish farmers have varying abilities to assess and improve these factors in their systems. Most farmers today utilize visual inspection to test water quality and conduct no extra treatment beyond periodically adding fresh water to the pond, often using fossil-fueled pumps.[82] We discuss the potential for mini-grids to electrify this water pumping below. **Pairing water-efficient recirculation systems with proper fish nutrition can reduce mortality, increase efficiency, and boost profitability of aquaculture systems, but would require significant capacity building to deploy in rural contexts.**[83] Lack of quality, cost-effective fish feed and shortage of quality, fast-growing fingerlings are two key barriers commonly recognized by the sector. We note that the quality of fingerlings correlates with water quality in hatcheries, which is also tied to recirculation practices.

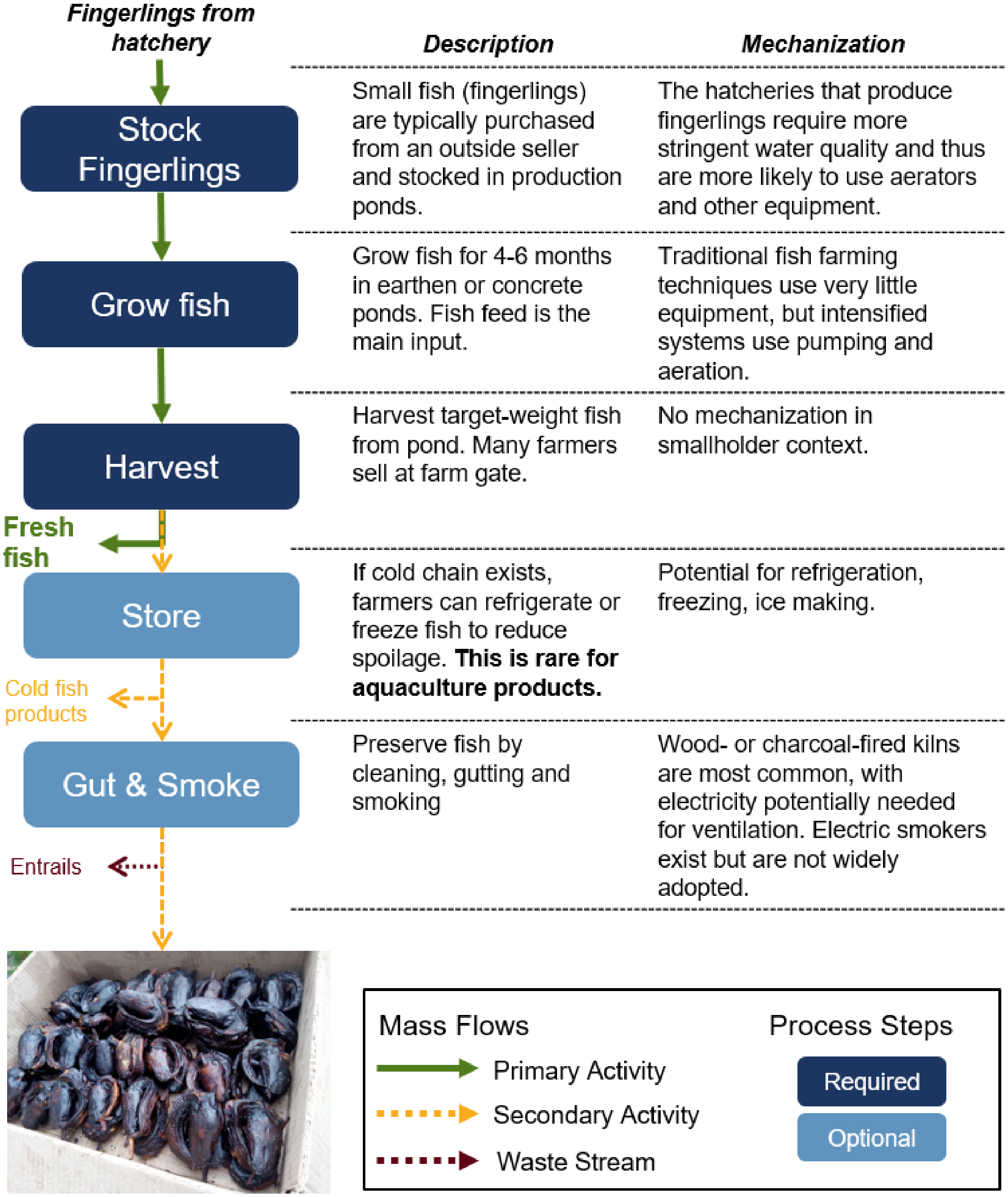
Beyond pumping, there is very little mechanization or cold storage involved in small-scale aquaculture today. Prior to smoking, fish are cleaned and gutted by hand. Smoking is performed with biomass heat in an oil drum, an oven, or an improved kiln. We present the aquaculture value chain fingerlings to smoked fish in **Figure 31**.

A.5.2.1 LOCAL TRADE

In rural Nigeria, fish trade tends to be hyper-local. Our survey indicates that roughly 80% of traded volume is purchased from local farmers and then sold fresh to local households within the community. The remaining market is presumably in smoked fish, which was also sold by some of the value chain actors we interviewed. Smoked fish are processed locally but can be sold farther beyond the community because of the added shelf stability of the dried product. Without the development of a cold chain or live-fish transportation capabilities it is unlikely that aquaculture trade can expand beyond this local scope.

Concrete catfish production pond in Bankpor community, Cross River state.

Figure 31: Aquaculture Value Chain from Fingerlings to Smoked Catfish



	Description	*Mechanization*
Stock Fingerlings	Small fish (fingerlings) are typically purchased from an outside seller and stocked in production ponds.	The hatcheries that produce fingerlings require more stringent water quality and thus are more likely to use aerators and other equipment.
Grow fish	Grow fish for 4-6 months in earthen or concrete ponds. Fish feed is the main input.	Traditional fish farming techniques use very little equipment, but intensified systems use pumping and aeration.
Harvest	Harvest target-weight fish from pond. Many farmers sell at farm gate.	No mechanization in smallholder context.
Store	If cold chain exists, farmers can refrigerate or freeze fish to reduce spoilage. **This is rare for aquaculture products.**	Potential for refrigeration, freezing, ice making.
Gut & Smoke	Preserve fish by cleaning, gutting and smoking	Wood- or charcoal-fired kilns are most common, with electricity potentially needed for ventilation. Electric smokers exist but are not widely adopted.

***Smoked catfish*:** N1200-1600/kg

Photo: @farmmarket_ng

A.5.3 Opportunities for Electrification in Aquaculture Production and Processing

Analyzing key considerations for aquaculture finds only Tier 2 (water pumping) and Tier 3 (cold storage, fish smoking) opportunities. These analyses are included below.

TIER 2

Water Pumping

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant

Local Know-How	◑	Most Nigerian fish farmers use extensive pond aquaculture systems. Only some farmers use mechanical water pumps. Introduction of higher-yield systems would entail more power use but would require substantial capacity building.
Offtake Market	●	Increased fish production enabled by better water quality can be solid in existing local markets.
Electric Equipment	◕	Electric water pumps are available in Nigeria, but care must be taken to procure a unit with a suitable capacity given pond volume, stocking rate and approach to water quality management.
Scalability	◔	Ponds located in mini-grid service territory could utilize electric water pumping. However, it is uncertain how much of Nigeria's 600,000 hectares of cultivation are located near town centers.

The pumping energy requirement for a fish farm depends on production system and degree of yield intensification. In Nigeria, nearly 80% aquaculture systems are extensive ponds: natural or man-made ponds where fish are stocked and fed under a low degree of environmental control.[82] Addition of fresh water to these systems is critical to ensure water quality and prevent fish fatality. However, the amount of water required for extensive ponds — and the energy associated with sourcing it — is dependent upon farmer management practices and the water resource environment.[84] Five of the seven fish farmers interviewed in Cross River state did not use any water pumping whatsoever. Expert interviews suggest that in many regions, fish farms commonly utilize ground-sourced pumps (e.g., "boreholes") to manage water quality and replace water lost to leakage and evaporation.[xliii] However, the actual energy use of these extensive systems tend to be very low when aeration pumping is not being utilized.[84] The exact extent of these practices and their associated energy use in mini-grid-suitable communities is unknown.

Introduction flow-through or recirculation aquaculture systems can intensify production and earn farmers more income per unit spent on hatchlings and feed.[83] These systems require significantly more power than extensive traditional pond aquaculture. However, new adoption of these systems would require capacity building to introduce local producers to best practices in pond design, stocking, nutrition, water quality monitoring, and harvesting.[85]

If a mini-grid is constructed in a community where local fish farmers are already using water pumping regularly, and if fish ponds are located within the service territory of the mini-grid, electric water pumping may offer cost savings for producers over petrol or diesel pumping (**Box A.5**).[86,87] However, because moving to these intensive aquaculture schemes will likely require extensive capacity building, and because the scalability across mini-grid sites is uncertain, we classify water pumping as a Tier 2 activity.

[xliii] Interviews with IFPRI-Nigeria, February 2020.

Box A.5 Mini-grid-powered pumps can reduce aeration operating costs 25% versus diesel pumps

Table 9: Cost of running diesel and electric aeration pumps to supply semi-intensive catfish production ponds. Costs are calculated for a system producing 1000kg of catfish per year, a representative value for a 1-hectare homestead system. Attribution of additional sources: [a] field survey data from diesel engine operators; [b] representative mini-grid electricity tariff in Nigeria in 2020; [c] based on repair and maintenance costs for diesel vs electric irrigation pumps.[86]

Cost of aeration for 1000 kg of catfish production per year:

	Diesel Pump		**Electric Pump**	
Pump field efficiency[87]	17%		84%	
Unit aeration energy requirement [84]	0.68	MJ/kg fish	0.68	MJ/kg fish
Actual energy requirement	0.11	L diesel/kg fish	0.23	kWh/kg fish
Unit energy cost	1.24[a]	$/L diesel	0.60[b]	$/kWh
Aeration energy cost	$134.64		$139.04	
Annual maintenance	$99.00[a]		$33.00[c]	
Estimated annual operating cost *to aerate 1000 kg of catfish production*	**$233**		**$172**	

Operators of semi-intensive catfish ponds can save roughly 25% on aeration operating costs by using mini-grid-powered electric pumps instead of old, inefficient diesel pumps **(Table 9)**. Electric pumps have a clear efficiency advantage over diesel options — especially those with engines beyond their service life and run at low capacity factors. This efficiency advantage allows electric pumps to compete on energy costs even at mini-grid tariffs approaching $0.60/kWh. Considering only energy costs, diesel and electric options are roughly comparable. But field survey results show that operators of these older diesel engines spend roughly $100 per year on engine maintenance and repairs. Even newer models of diesel pumps require roughly 3x the annual expense on maintenance compared to electric models.[86] These savings make mini-grid-powered electric pumps the clear least-cost option, and only become more cost competitive as mini-grid tariffs come down, perhaps as mini-grid developers issue time-of-use discounts to encourage afternoon power use.

However, most Nigerian catfish farms today do not incorporate aeration into their aquaculture systems.[79] Although aeration can be an important part of water quality management for optimal performance, most traditionally practicing fish farmers do not utilize it. Mini-grids in communities with strong aquaculture sectors may consider partnerships with agricultural development actors who have an interest in capacity building, citing reduced pumping costs as a clear benefit of collocating their efforts.

TIER 3

Cold Storage for Farmed Fish

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Know-How	◑	Farmers and traders responded interest in cold storage, but none had experience in integrating the cold chain into their fish selling practices.
Offtake Market	◔	Customers have a strong preference for local fish species, especially catfish, to be sold fresh. Integration of the cold chain into local fish marketing requires careful navigation of customer tastes.
Electric Equipment	●	Electric refrigerators, freezer, and ice makers are commonly available in Nigeria.
Scalability	◔	Aquaculture is already one of the least prevalent value chains studied, and consumers' preferences around fish freshness will likely vary across geographies and cultures.

Introducing cold storage presents potential value add for fish farmers and traders, from reducing fish spoilage post-harvest and allowing fish to be sold to markets farther beyond the community in which they are produced. But as described above, there is strong cultural preference for aquaculture species to be consumed fresh, without any refrigeration or freezing. These consumer preferences are markedly different for fish that are captured from natural fisheries such as lakes, rivers, and oceans. Refrigeration or freezing is much more common for wild-caught fish or shellfish as the products are typically killed much earlier in the value chain and thus began to spoil earlier. **Mini-grids that are located near these natural fisheries may find existing demand for cold storage without any capacity building or market development. In these cases, cold storage is a Tier I opportunity for electrification with mini-grids.**

100% of aquaculture value chain actors interviewed speculated that refrigeration would allow them to increase their earnings by allowing more fish to be sold fresh, rather than smoked. However, 0% of these actors had prior experience with cold storage.

Given the hyper-localized nature of fresh fish markets in Nigeria, some have speculated that cold storage could allow aquaculturists to connect to higher paying markets farther beyond community borders. The availability of cold storage within these communities is a necessary – but not wholly sufficient – condition to enable this improved market access. Full cold chain infrastructure is required maintain preservation along the value chain, from rural communities to larger hubs. When aquaculture value chains are confined to local areas because of this lack of regional cold chain infrastructure, it is uncertain whether there will be enough local market demand for refrigerated or frozen fish to support investment in cold storage or ice making. **Aquaculture experts suggest that capacity building and extension services can sensitively adjust consumers' preferences for cold-stored fish, connect producers to urban markets, and arm local actors with best practices for filleting and food safety.**[xliv] If such programs are implemented by agricultural development stakeholders, mini-grids could be beneficially collocated with these potential new sources of electricity demand.

[xliv] Interviews with IFPRI-Nigeria, November 2019.

Fish are highly perishable, and cold storage is one way to preserve the product between harvest and sale. Presently, the prevalence of alternative fish preservation practices (i.e., fish smoking), lack of cold chain infrastructure, and consumers' strong preference for fresh catfish challenge the viability of refrigeration/freezing of aquaculture products as a productive use for mini-grids. Based on these considerations, we classify cold storage for fish as a Tier 3 activity.

Electric Fish Smoking

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Know-How	◑	Processors smoke or dry fish but do not have experience with electric smokers.
Offtake Market	◕	Smoked fish can be sold locally or in markets a great distance from producing communities.
Electric Equipment	◔	Electric kiln smokers are commonly sold throughout the world, but their availability in Nigeria is uncertain. Consumers may prefer wood-smoked fish to electric-smoked.
Scalability	◕	Fish smoking is prevalent throughout aquaculture communities and adoption could be high were a cost-effective electric smoker developed.

Fish that cannot be sold fresh are smoked to preserve them. Smoking costs are estimated at 700 N/kg smoked fish, and the process boosts fish price from 450–600 N/kg to 1200–1500 N/kg.[75,79] Because about 40% of the fresh fish weight is lost when the fish is gutted for smoking, these prices make the cost of smoked fish roughly comparable to fresh fish. For this reason, fish smoking is seen more as a means to reduce post-harvest losses than a value-add activity. If smoking costs are significantly reduced by mechanization or innovation, this could change. Though traditionally smoked fish are acceptable to consumers, established methods often lead to post-harvest waste and poses food safety risks when the fish moisture content is not reduced to proper levels.

Women dominate fish smoking, which is typically conducted over traditional wood fires for 1–3 hours per batch.[79] The negative health effects of traditional smoking are clear: one study found an 9x increase in incidence of chronic bronchitis in women with long term occupational exposure to burning firewood, compared to a control group.[88] Reduction of smoke exposure is a significant public health challenge for this group.

Affiong Asuquo Ekpo preparing to smoke catfish in Ifondo community, Cross River.

Improved smoking kilns have been developed to increase efficiency, safety, and quality. One study in Lagos state found that 90% of processors were aware of improved smokers, but only ~20% utilized them due to lack of capital or access to appliance markets that sold the improved equipment.[89] None of the processors in this survey utilized electric smokers, with many citing concerns about the ability of these devices to replicate wood-smoked flavors. There is some low-level adoption of solar dryers which can preserve fish using passive solar energy but require a 7–10 day drying period.[90] Electrification of fish smoking would require local processors to adopt new cooking technologies, a behavior change that has eluded development programs for decades. Although electric smokers are readily available on the international market, it is less clear whether these devices will satisfy consumer preferences or be cost-competitive with traditional practices. To deploy electric fish smoking at scale would require further research and analysis of suitable electric dryers as well as capacity building to support adoption.

Finally, when it comes to supplying heat for a process like fish smoking, mini-grid electricity is at a comparative disadvantage with biomass burning (see **Box A.4** in **Section A.4.3**, which discusses this fact in the context of rice parboiling). Transforming electrical energy to heat sacrifices all of the exergy (quality of energy) that allows electricity to power pumps and motors so efficiently. Trying to make mini-grid-powered resistive heaters compete with nearly-free biomass for fish smoking is not a good use of time or effort for early productive use stimulation efforts. We classify this activity as Tier 3.

A.6 *Cocoa*

- **Cocoa is a cash crop that plays an important role in agriculture exports**. But national yields and production are in decades-long decline.
- **The most profitable value-add steps in the global value chain are in processing dried cocoa beans**. Nigerians' earnings come mostly from the sale of primary production in the form of dried beans, with very little local value add.
- Smallholder-produced cocoa beans are a low-volume, high-value commodity, meaning **manual processing is less profitably mechanized at the community level**.
- **Top priorities for development of the cocoa industry are improvement of smallholder yields and market bargaining power, which are not energy-related challenges.**
- **There is no near-term case for integration of mini-grid electricity into local cocoa value chains.**

A.6.1 Crop Background and Market Characteristics

Cocoa beans are the dried and fermented seeds of cocoa (cacao) tree fruits. Cultivation and harvest of cocoa requires tedious manual work as farmers plant, weed, prune, and harvest cocoa trees; and harvest, collect, extract, ferment and dry beans from the cocoa fruits. The world's cocoa production is dominated by countries with equatorial climates suitable to the tree, and supply of low-cost labor to perform these manual tasks. West African countries account for roughly 70% of global production.[91]

Cocoa trees usually begin to bear fruit after 3–4 years, reach peak production around year 10 and can yield pods for 30–40 years.[92] Cocoa pods take about 5–7 months to ripen before farmers harvest them with long handled tools. The main harvest can last for a few months although pods might be ready for harvest any time of the year. Changes in weather can affect harvest time.

Ripe pods are broken to remove beans inside, which are then fermented to develop flavor, and then dried. Dried beans from an average pod weigh less than two ounces and about 400 beans are required to make one pound of chocolate.[92]

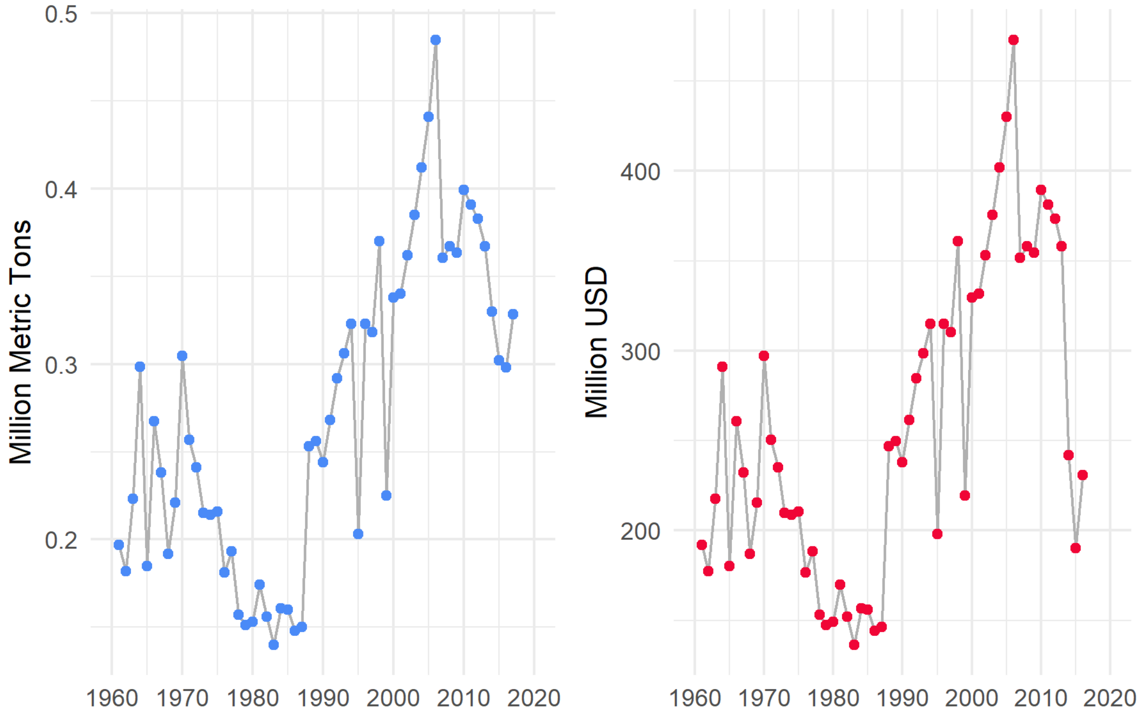
Odido Celestin and his cocoa tree in Ojerim Mbube community in Cross River state. He farms 2 hectares of cocoa trees and sells sun-dried cocoa beans to traders in the community. He says a lack of access to financing prevents him from expanding his business by planting new cocoa trees.

Total cocoa production has fallen steadily since 2006 and Nigeria lags West African nations in productivity: the national average ranges from 0.2–0.5 metric tons per hectare.[10] The factors causing low productivity include aging of cocoa farmers and cocoa trees, pest and disease, and low adoption of intensive cultivation practices.[91] IFPRI's cocoa yield forecast predicts that Nigeria cocoa yields are unlikely to exceed 0.60 metric tons per hectare by 2050 (compared to 3–5 metric tons per hectare under experimental conditions).[93] As climate change increases maximum dry season temperatures, Nigerian cocoa is particularly vulnerable to further yield reduction without proper adaptation.[94] Improving primary productivity of cocoa is the central focus in Nigerian cocoa development: several efforts aim to improve smallholder yields in West Africa, including the World Cocoa Foundation's Cocoa Livelihoods Program and the African Cocoa Initiative, in which Feed the Future is a key partner.

Nigeria is fourth largest producer of cocoa beans in the world behind Cote d'Ivoire, Ghana and Indonesia, with estimated national production of about 332,000 tons in 2018 (**Figure 32**).[10] This falls well short of the target for production of 500,000 tons by 2015 and 1,000,000 tons by 2018 set in the federal government's Cocoa Transformation Action Plan.[95]

Cocoa is only grown in Nigeria's humid agroecological zones, and the South West region is the hub of cocoa production. One in five communities we surveyed in Cross River cited cocoa as a major crop grown by more than five farmers. There are about *30,000 farmers* who grow cocoa in 14 states across Nigeria, the majority at small-scale.[96] For scale, consider that an estimated *9 million households* cultivate maize.[27] Cross River, one of the states we surveyed for the demand stimulation study, accounts for about 18% of the cocoa production in Nigeria[97].

Figure 32: Gross National Production (Left) and Gross Value (Right) of Cocoa Beans in Nigeria[10]



Production has steadily declined since the mid-2000's. The acute dip in cocoa production during 2014–2015 has been attributed to unfavorable weather conditions: a severe harmattan that reduced quantity and quality of harvested beans.

About 70% of cocoa beans are exported in the form of dried beans without any processing, and the rest are processed into cocoa powder, butter, and paste domestically.[96] 90% of these domestic derivatives are then exported; Nigerians only consume about 3% of cocoa beans production as food within the country.[98] In 2016, cocoa generated $698 million in export value, leading agricultural exports but still worth just 1/100th of the value of Nigeria's petroleum exports.[99]

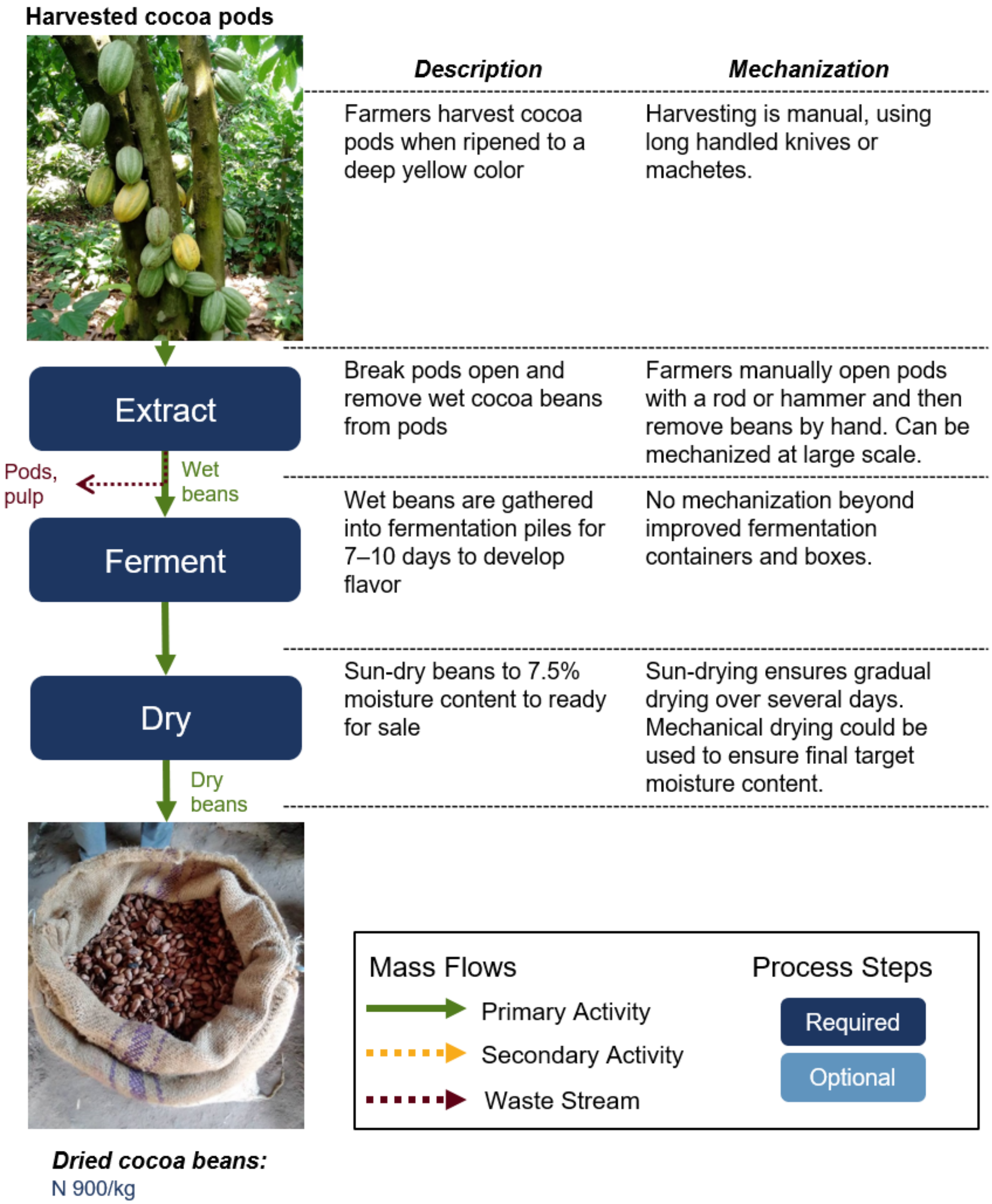
A.6.1.1 POST-HARVEST LOSSES

Post-harvest losses are not a major factor for local cocoa farmers and traders. Incomplete drying from air-drying in humid environments can contribute to storage losses or quality degradation, but these would be observed further along the value chain, when aggregators or offtakers are storing the beans prior to processing them. Only one farmer among 20 surveyed reported about 8% of spoilage, and no traders reported any spoilage while the beans were in their possessions. Local markets are also not sensitive to bean quality, so farmers do not have reason to ensure the precise dryness of their product.

A.6.2 Value Chain Description

Figure 33 presents the activities flow happening within mini-grid-suitable communities, from harvesting cocoa pods to trading dried beans. Further processing of cocoa into powder, butter, paste, or other derivatives is mostly conducted in facilities with capacities denominated in the ten-thousands of tons and is not a viable value-add activity for mini-grid communities.[96] **Box A.6** provides further discussion on the prospects of local cocoa processing.

Figure 33: Summary of Cocoa Value Chain Within Rural Nigerian Communities



Description	***Mechanization***
Farmers harvest cocoa pods when ripened to a deep yellow color	Harvesting is manual, using long handled knives or machetes.
Break pods open and remove wet cocoa beans from pods	Farmers manually open pods with a rod or hammer and then remove beans by hand. Can be mechanized at large scale.
Wet beans are gathered into fermentation piles for 7–10 days to develop flavor	No mechanization beyond improved fermentation containers and boxes.
Sun-dry beans to 7.5% moisture content to ready for sale	Sun-drying ensures gradual drying over several days. Mechanical drying could be used to ensure final target moisture content.

A.6.2.1 LOCAL TRADE

Farmers prefer to sell dried beans to Local Buying Agents (LBAs) and cooperatives, to reduce transportation cost and chances of their beans getting rejected by buyers because of subpar quality. LBAs and cooperatives will then sell beans mostly to merchants who quote higher prices.[96] In our survey, **all local cocoa traders purchased fermented, sun-dried beans from local farmers and passed them on to other traders or aggregators**. Some of these aggregators are directly associated with one of Nigeria's large domestic processors. All value chain actors surveyed reported that cocoa only left the community as sun-dried beans.

Cocoa farmer Odima tiku Odo's beans drying in the sun in Adijinkpor community in Cross River state.

Akpere Ejah Frances, a cocoa trader in Bankpor community in Cross River state. He purchases fresh beans from farmers, dries them and sells to other traders and small processors.

Opportunities for Electrification in Rural Cocoa Value Chains

From literature review, expert interviews, and survey data, no Tier 1 or Tier 2 activities have been identified. Mechanical drying of locally produced cocoa beans is classified as a Tier 3 opportunity for mini-grids.

TIER 3

Mechanical Cocoa Bean Drying

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Know-How	◔	Cocoa beans are typically sun-dried, which limits the intensity of heat applied. Mechanical drying methods require careful monitoring and operation to prevent quality degradation by over-heating.
Offtake Market	◑	There is unmet export demand and domestic processors have the capacity to process more cocoa beans given that current utilization rate is low. However, local markets may not have the capacity to detect small improvements in dryness. Traders who pay for cocoa by unit mass may inadvertently penalize farmers bringing drier (lighter) beans.
Electric Equipment	◑	Existing mechanical dryers are mostly heated by combustion, with limited electricity requirements. Electric options are available but are likely cost-prohibitive to run at mini-grid tariffs.
Scalability	◔	Cocoa production in mini-grid-suitable communities is often small relative to other crops, in part because of Nigeria's low-yielding tree stocks and management practices.

Every cocoa value chain actor surveyed during this study reported that cocoa beans left the community only after sun-drying. Cocoa beans are ideally dried from ~60% moisture to ~7.5% moisture levels.[100] All cocoa farmers interviewed in this study reported sun-drying their beans. About 80% of respondents report that they experience problems drying their cocoa beans at least one day per season, with roughly 50% experiencing this problem for 10–20 days during the harvest **(Table 10)**. However, only one respondent reported spoilage as a result, and no farmer was unable to sufficiently dry their cocoa before sale.

Alternative drying methods may offer benefits to these farmers, especially when high humidity and seasonal rains affect open-air sun-drying, as in southern Nigeria's cocoa-growing zones. Forced air mechanical dryers are used in larger production centers around the world, typically using a fan to move combustion-heated air through a bed of drying beans.

Table 10: Cocoa Farmer Interview Responses on The Effectiveness of Air Drying

<table>
<tr><th colspan="2">Cocoa farmers using air drying: How frequently do you experience drying problems during the busy season?</th></tr>
<tr><td><i>Response</i></td><td><i>Frequency</i></td></tr>
<tr><td>Never</td><td>18%</td></tr>
<tr><td>One or two days per season</td><td>27%</td></tr>
<tr><td>Three to ten days per season</td><td>10%</td></tr>
<tr><td>Ten to twenty days per season</td><td>45%</td></tr>
<tr><td>I am not able to sufficiently air-dry my cocoa during the busy season</td><td>0%</td></tr>
</table>

Offtakers expressed concern that the use of mechanical dryers may compromise the value chain in a variety of ways. The presence of artificial drying may cause the fermentation process and drying to be rushed, thus decreasing the flavor quality of the beans.[xlv] Artificially dried beans may resemble traditionally processed beans on the outside, but rushed fermentation can embitter the product, and drying at high temperatures may allow the surface moisture content to reach the target while the inner bean is still wet.[100] Such incompletely dried beans mold further along the value chain, as the moisture migrates from the interior to the dry outer surface. Additionally, studies show that acetic acid levels can rise to suboptimal levels at increased mechanical drying temperatures.[101] Offtakers also warned that the grading practices in local cocoa offtake markets are not sensitive enough to moisture content to value the slight improvement that mechanical drying might provide. Traders who pay for cocoa by unit mass may even inadvertently penalize farmers bringing drier (lighter) beans.

For cocoa-producing communities that want to protect beans from the rain and improve drying speed by 40%, a simple greenhouse-style solar dryer can be constructed for less than $50 by covering a locally-constructed frame with polyethylene film.[102] These solar drying houses also protect the beans from direct solar radiation and environmental contaminants, all at zero operating cost.

For the above reasons, **it is not likely that mechanical drying will cost-effectively dry small volumes of cocoa beans produced by smallholders. It is even less likely that mini-grid-powered drying will be economically viable given the relatively high electricity tariff and uncertainty around the price premium received for precisely dried beans.** Therefore, we classify mechanical cocoa drying as a Tier 3 activity.

[xlv] Interview with Tropical General Investments, February 2020.

Box A.6: Further cocoa processing is not viable in mini-grid-suitable communities without significant changes in local capacity or outside investment.

The cocoa value chain can be roughly subdivided into 3 sections: production, intermediate processing, and final product processing. Cocoa production is performed at the smallholder level, as described above, and nearly always ends at the dried bean stage. Traders aggregate smallholder production and pass the beans on to intermediate or final product processors.

Intermediate processing operations roast and grind dried beans to convert them into cocoa butter and cocoa powder.[100] The study team has not been made aware of any intermediate processing that is occurring in mini-grid-suitable communities. All cocoa value chain actors surveyed had no knowledge of cocoa processing capacity within their community or within other larger communities.

Chocolate manufacturers combine these intermediates in various proportions and incorporate other ingredients, such as milk and sugar. Some manufacturing operations source dried beans directly and perform intermediate processing as well. This final stage of value addition is capital-intensive, complex, and requires expert design and operation.

Four large multinational companies control over 60% of global cocoa processing, and vertical and horizontal integration is increasing.[103] Currently, Nigerian processors are only utilizing 9%–25% of processing capacity, meaning there is significant idle capacity at industrial-scale facilities to offtake any increase in cocoa production.[104]

Local processing is unlikely to be viable at the second and third value-add stage. This status quo leaves farmers with just 8 cents for every $1 of chocolate sold.[92] **However, cocoa experts do not recommend localization of processing as a means to democratize value creation in the supply chain.** Instead, they advocate for interventions that improve the productivity and bargaining power of smallholders.[103] Such measures may include intensification of farming practices,[105] reinforcement of competition laws, boosting market transparency, introducing farmers to risk management instruments, and strengthening grading practices to fairly compensate high value beans. These changes are not directly tied to electrification or productive uses of electricity.

A.7 *Milk*

- **In some regions and cultural groups, dairy farming is a critical component of cultural and economic life.** Mini-grids operating in Middle-Belt or Northern states with large numbers of Fulani pastoral communities are most likely to encounter concentrated milk production.
- **Domestic milk production is less than 50% of demand.** To compensate, many commercial dairy processors are investing in local offtake supply chains in addition to importing powdered milk to serve their operations.
- **Milk chilling is a promising activity where offtaker interventions, local milk production, and mini-grids intersect.** However, milk collection centers require investment by offtakers or other dairy experts and only occur within the catchment area for nearby dairy processing plants.
- **Without significant development of local dairy values chains from dairy farming practices, transport infrastructure, and offtake markets, the milk value chain will not present widespread opportunities for productive use of mini-grid electricity.**

A.7.1 Crop Background and Market Characteristics

Cattle, sheep and goats provide income, draft power, manure, insurance and nutrition for millions of Nigerians.[106] For the pastoral Fulani (*Fulbe*) people who reside in the Sahelian regions of western and central Africa, cattle are an indispensable component of livelihoods, culture, and tradition. [107] In northern Nigeria, some Fulani communities maintain a nomadic lifestyle, moving their herds between natural grazing areas. Around 82% of cattle are raised in these extensive production systems, while agro-pastoralists who tend crops in addition to cattle account for another 17%.[108] Around 50% of cattle owners consume dairy on a weekly basis, though milk may not always be available due to inconsistency in cows' production. One survey of Fulani dairy farmers showed meat to be consumed infrequently, while milk consumption averaged 0.5–0.7 liters per person per day.

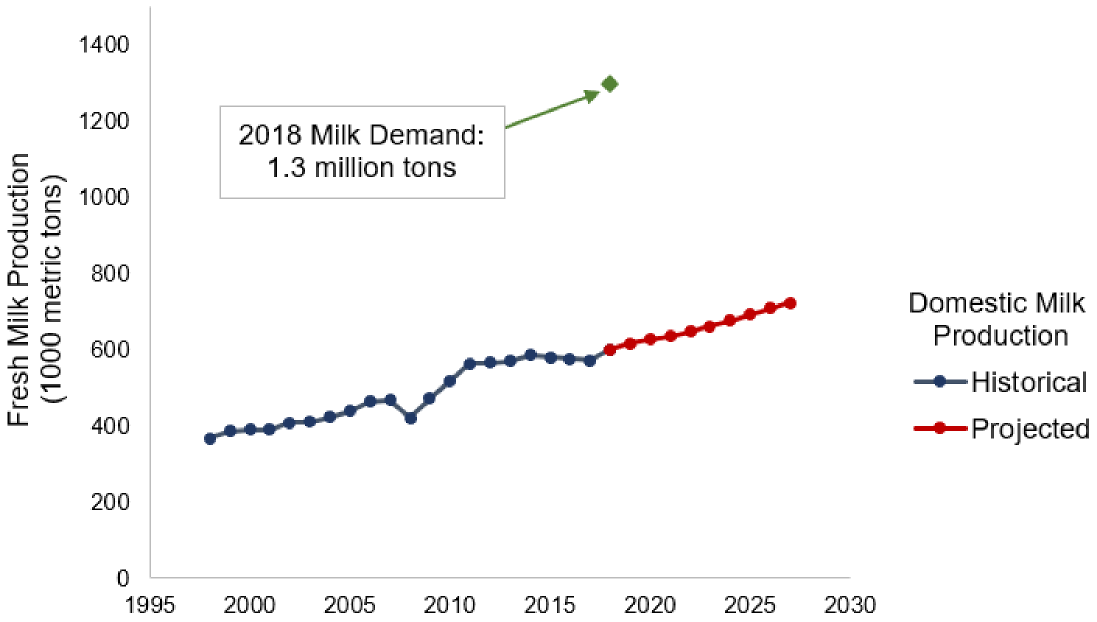
This study focuses on the opportunities to integrate mini-grid power into cow's milk value chains rather than meat production and processing. Milk is the most perishable commodity in this study, requiring cooling within 3–4 hours of milking to avoid deterioration according to international food standards.[109] Once milk has degraded to poor quality, it cannot be corrected later in the value chain, though some may be salvaged into cheese. Post-harvest milk losses are estimated conservatively at 20%.[110] An average Nigerian cow may produce 213 kg of milk in one year, and milk chilling operations (discussed below in **Appendix A.7.3**) may handle hundreds of liters of milk per day from a group of pastoralists.[110]

A young Fulani woman selling Fura da nono, a popular Northern drink that combines seasoned millet balls with locally fermented milk. Here, she stops to make a sale along the road to a nearby community market. Without refrigeration, whatever is not sold today must be consumed by family or friends or discarded.

In dairy-producing families, women are typically responsible for milk collection and handling. Men tend to maintain ownership of cattle, but a 2018 survey in Kano and Oyo states found that **more than half of women reported having control over milk-derived income**.[111] Although these trends may vary across regions and cultures, this gives dairy value chain initiatives unique potential to empower Nigerian women. Of course, without deliberate efforts to ensure women maintain power over milk-derived income once the value chain has developed, these positive effects may not be achieved.

Most milk production comes from producers utilizing low-productivity practices: the typical productivity of a Nigerian cow is one tenth of the global average.[106] These lower yields are in large part because free ranging dairy cattle are fed and watered opportunistically, with limited access to improved pastures or supplemented feed to maintain consistent nutrient intake.[108] Use of low-yielding indigenous cattle breeds, traditional husbandry practices, and lack of access to veterinary care also limits smallholders' production. Commercial dairy systems achieve 10,000–15,000 L/cow/year through intensive management practices,[112] but commercial systems account for just 5% of Nigerian milk production.[108]

Figure 34: Nigerian Milk Production Versus Milk Demand[108,113]



There is strong unmet demand for domestic milk production by both Nigerian households and processors. 60% of Nigeria's 1.3 million ton annual demand for milk is imported **(Figure 36).**[108] Today, a large fraction of this unmet demand is supplied as powdered milk. Even commercial dairy processors must often resort to importing powered milk, reconstituting it, and then utilizing it to create yoghurt, ice cream and other products.[110]

One projection shows **Nigerian dairy consumption increasing 577% by 2050**, more than five times the anticipated growth in beef demand.[114]

Responding to this growing demand is a core component of the federal government's National Livestock Transformation Plan. In 2019, the Central Bank of Nigeria limited access to foreign exchange for milk importers and offered low-interest loans to milk producers in hopes of promoting domestic production. By February 2020, six firms — including Nestle Nigeria, FrieslandCampina, and Arla — had already been granted exceptions from these restrictions.[115]

The domestic milk shortage is exacerbated by weak milk supply chains that fail to connect rural milk producers to larger markets and commercial processors. Most pastoral or agropastoral milk processors are not able to move their milk from the pasture to faraway markets because of deficits in transportation and cold storage infrastructure. Private dairy companies have engaged in a variety of milk value chain development programs with the intention of increasing the amount of milk that can be sourced locally. These procurement targets can be large: FrieslandCampina WAMCO Nigeria Ltd aimed to source 60 million liters of raw milk by building milk collection centers to aggregate, test, and safely store milk from local herds.[116] Several other processors or cooperatives run similar milk supply chain operations, including MILCOPAL, Arla, and L&Z, but these interventions do not serve the vast majority of Nigerian dairy farmers to date.

Development initiatives have shown that given comprehensive support, rural milk production can be integrated into modern dairy supply chains. A prime example is the Nigerian Dairy Development Program (NDDP), a partnership between FrieslandCampina, the Federal Ministry of Agriculture and Rural Development, and development partners aiming to improve dairy practices in several states.[117] NDDP is a processor-led intervention that includes local capacity building among Fulani farmers, milk offtake and transportation, and collection centers equipped for quality control testing to support the supply chain for their Nigerian processing facilities. It is not clear that these dairy supply chains can connect to rural communities without this level of buy-in and support from a large offtaker.

A.7.1.1 Post-Harvest Losses

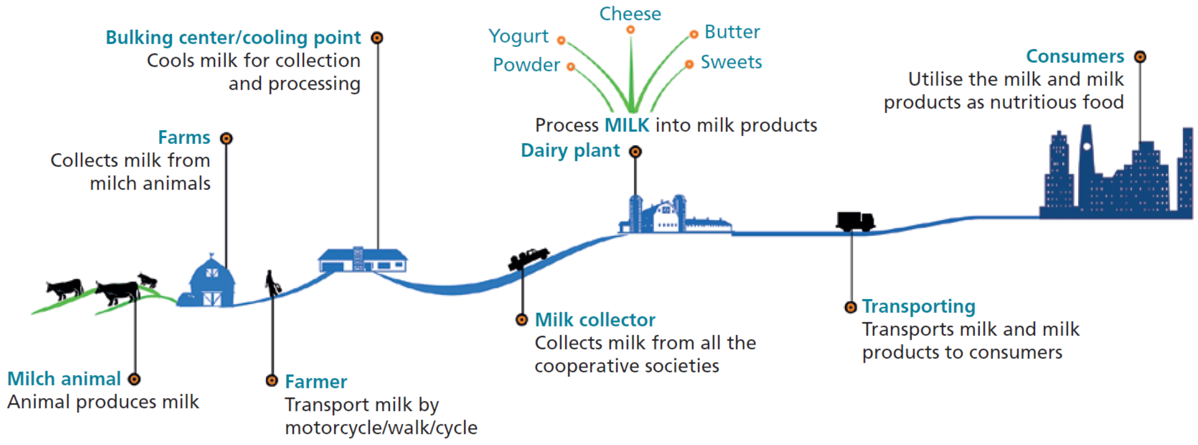
Milk is the most perishable commodity in this study, requiring cooling within 3–4 hours of milking to avoid deterioration according to international food standards.[109] Post-harvest milk losses are estimated conservatively at 20%. [110] Even milk that makes it to milk collection centers may be discarded as a result of contamination or quality issues: the National Livestock Development Program's milk collection centers reported selling only 90% of the milk it purchased.[116]

A.7.2 Value Chain Description

The milk value chain entails milk harvest, transport, processing, and sale **(Figure 35).** Our dairy farmer interviews find that most farmers consume a significant portion (~45%) of daily milk production themselves, leaving just a few liters per day available for sale. In the long term, the amount of milk available for sale would increase as smallholders' milk yields improve. **Appendix A.7.2.1** describes the today's local milk marketing practices. The supply chain for locally marketed milk requires no mechanization, although basic refrigeration would reduce spoilage at the smallholder level.

Moving from small-scale local dairy trade to a formalized industry supply chain stands to improve incomes, generate off-farm jobs, and improve value chain efficiency by reducing post-harvest losses. Milk collection schemes are the core component of this next stage in dairy development, providing the means to preserve milk quality from farmer to processing facility.[118] The lack of milk collection infrastructure is a major obstacle to the development of dairy value chains in mini-grid-suitable communities.

Figure 35: The Milk Value Chain from Production to Consumer



Excerpted from Moffat et al., 2016.[118]

The mechanism of dairy transport depends on the level of formalization of the value chain, and the distance between the farmer and the milk collection center.

- **L&Z Integrated Farms Nigeria Ltd.**, a commercial milk processor based in Kano, buys milk directly from farmers at the collection center location.[xlvi]
- **Arla**, the Danish Dairy Cooperative, also sources fresh milk from clusters of local farmers who supply its milk collection centers.[xlvii] Their Milky Way Partnership organized offtake agreements between Arla and local cooperative partners to provide a bridge to smallholders who otherwise would not engage with the formal supply chain. Arla also offtakes from larger pre-existing dairy cooperatives, some of which are close enough to processing centers for milk to skip chilling in collection centers and be transported straight to the factory.
- **FrieslandCampina,** through the NDDP value chain, procures milk by sending motor bike collectors to dairy communities equipped with specialized canisters that store milk safely until delivering to a collection center later in the morning.[117]

At the collection center, the milk is tested for quality, chilled to suitable conditions in a specialized milk chiller (described in detail below) before the final leg of transportation to the processing facility. Commercial dairy operations produce and package fresh pasteurized milk, yoghurt, cheese, *Fura da Nono*, and ice cream, which sell at healthy margins in urban centers.

To date, few farmers and farmer groups have been able to sustain milk transport and collection schemes without heavy external support from offtakers like these.[110] None of the dairy farmers we surveyed had access to these milk storage facilities within their community or a nearby community.

A fresh milk sale underway in a peri-urban community in the Federal Capital Territory.

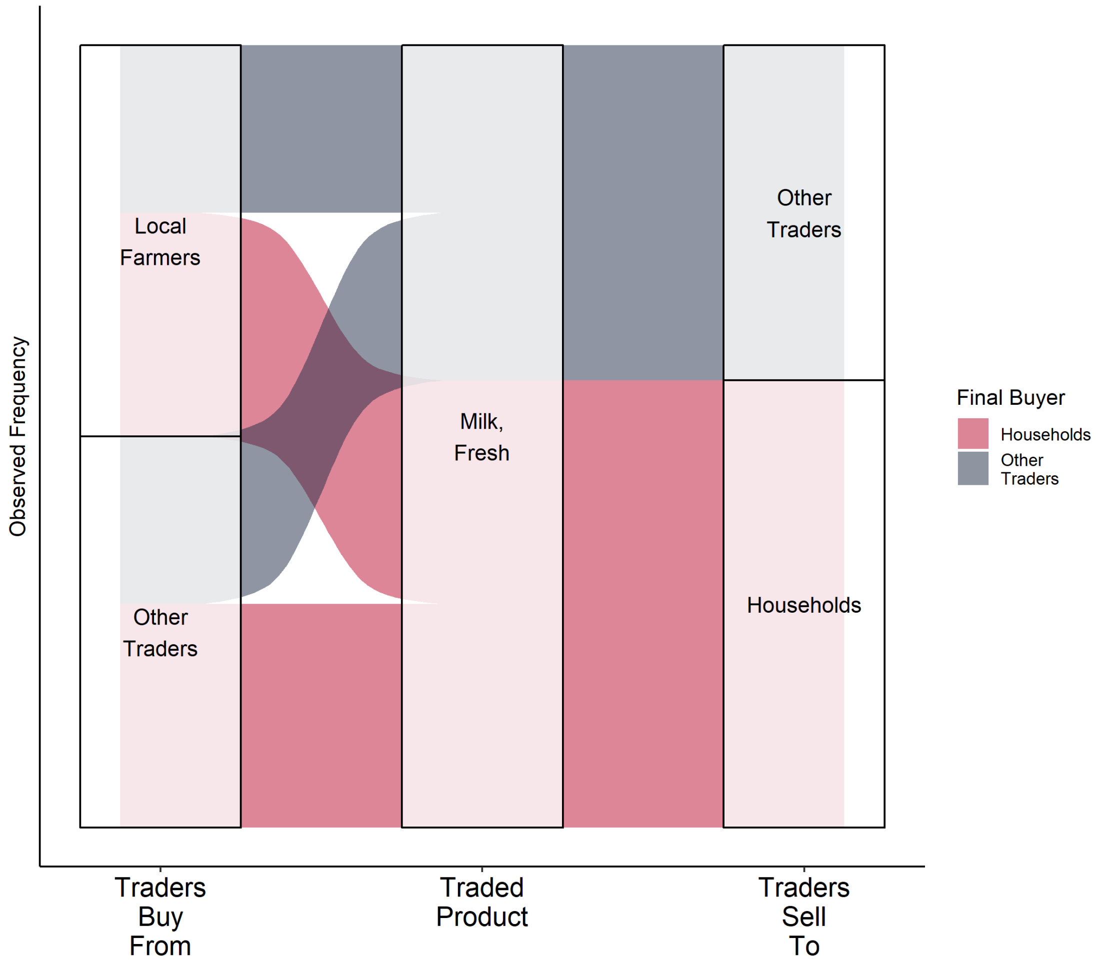
[xlvi] Interview with L&Z Integrated Farms Nigeria Ltd., February 2020

[xlvii] Interview with Arla Milky Way Partnership, February 2020

A.7.2.1 LOCAL TRADE

Milk sales and consumption tend to be hyper-local. Today, women dairy farmers sell surplus milk in local markets themselves (see photo above), or to local traders **(Figure 36).** When traders do not arrive to offtake the milk, it is up to these women to find a buyer themselves, which can be time-consuming and expensive after accounting for transportation costs.[117] In some communities, local processors create cheeses and yoghurt products for sale in nearby markets, as one survey in Oyo state found.[119] Our survey did not identify any of these processors in milk-producing communities in Kaduna, but more much more extensive surveying would be required to accurately assess prevalence of offtake from local processors.

Figure 36: Local Trade Flows for Fresh Milk in Surveyed Communities



Flow size is proportional to the likelihood of the trade from source to final buyer.

A.7.3 *Opportunities for Electrification in the Milk Value Chain*

There are no Tier 1 or Tier 2 activities identified for milk value chains. Analysis of bulk milk chilling centers using our prioritization criteria showed that significant support is required to support implementation in mini-grid-suitable communities. We classify milk chilling as a Tier 3 opportunity.

TIER 3

Milk Chilling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Low milk yields limit the volume that can be offtaken, and most local value chain actors are not accustomed to milk transport and chilling operations. Significant capacity building required to ensure hygienic practices from milking to storage.
Offtake Market	◑	Milk offtakers in Nigeria have strong demand for fresh domestic milk but struggle to source from disparate dairy herds.
Electric Equipment	◕	Milk chillers are internationally available, standardized pieces of equipment that are best operated on stable electricity connections that mini-grids offer.
Scalability	◔	Success requires a rare combination of a willing offtaker, dairy capacity building programs, and a mini-grid site within a strategic catchment area for a milk collection center.

Significant external support is needed to orchestrate milk transport and storage schemes. Thus, the opportunity for mini-grids to power milk chilling depends upon the presence of an offtaker who is committed to developing a fresh milk supply chain. If an offtaker such as those described above is willing to invest in commercial-scale milk collection infrastructure, then they will likely require a milk chilling device as discussed in this section. If there is no such offtaker, then small-scale refrigeration may still offer some benefit to local dairy value chain actors. However, the load of refrigeration to serve low-volume hyper-local milk storage is unlikely to be more significant than that of a typical bar or restaurant, and thus is not considered a key productive use in this study.

Ideally, warm, fresh milk is cooled immediately after harvest to ~10°C,[120] though performing this cooling at the smallholder level does not appear to be standard practice even in offtaker-led supply chains. If commercial processors are engaged in the milk value chain, then international food standards mandate that milk must be cooled to 4°C within three to four hours of harvest.[109] For fresh milk that is at atmospheric temperatures of 25–30°C, this presents a significant cooling demand up to twice per day per farmer. The absolute energy requirements for milk chillers to meet this cooling load depend on their scale, but even the largest milk cooling tanks could be powered by a mini-grid as an anchor tenant. A small milk collection point might have a 400 L capacity, with capacity utilization ranging between 40%–95% depending on the time of year — the dry season curtails production as feed availability falls.[xlviii]

Electric milk chillers are a standard piece of equipment for commercial dairy farmers and hundreds of models are available on the global market.[xlix] The exact design of the equipment will depend on the capacity requirements of local milk production, the expertise of the system operator, and the offtaker's assessment of capital vs operating cost tradeoffs.

[xlviii] Interview, Anonymous Offtaker, February 2020.

[xlix] ISO 5708:1983 governs refrigerated bulk milk tanks.

Illustration of an open-top direct expansion milk chiller, excerpted from Moffat et al., 2016.[118]

Open-top direct expansion chillers are the simplest and most common model at the Nigerian scale of aggregation (200–2500 L, see above). In these models, milk can be poured in directly via a lid rather than requiring pumps. Most refrigeration systems require a continuous supply of AC power to operate a vapor compression cooling cycle, at roughly 20 Wh/L of milk.[118] **For a system processing 300 L of milk daily, this cooling load translates to 6 kWh/day of predictable power demand.** Mini-grids stand to provide this power supply at a cost competitive with diesel generation in addition to reducing the operational complexity for the offtaker, who is not typically an off-grid power expert. [118]

All modern milk chillers are well-insulated to keep milk cool without continuous refrigeration. For some installations, energy efficiency improvements such as pre-cooling incoming milk with nearby well or surface water may reduce refrigeration load and reduce mini-grid electricity costs for the operator.[118] Likewise, time-of-use mini-grid tariffs could incentivize chillers to super-cool during afternoon hours when solar power is most abundant, effectively "charging" the tank like a battery. Strict temperature tolerances would need to be enforced to avoid over- or under-cooling the product. Alternatively, a heat transfer fluid such as a tank of water or an ice bank could be preemptively chilled when time-of-use tariffs are low and then utilized to pre-cool milk before refrigeration. These advanced efficiency measures are likely realistic only when partnering with experienced industry players.

If milk chilling operations were found to occur in prospective mini-grid communities, the loads would almost certainly be cost-effectively served by mini-grids. However, a very specific set of criteria must be satisfied for a milk collection point to be built today, including interest from a dairy offtaker, a capacity building program for the local community, and a mini-grid site within the offtaker's catchment area. When these criteria are met, milk chilling facilities can be ideal anchor loads for mini-grids.

A.8 *Cashew*

- **Mechanized cashew processing requires a rural factory operating a suite of processing equipment with the expertise to meet stringent quality standards.** [I] Cashew kernels are a luxury good that demand high quality for a premium price. This makes it difficult to localize production — without strict quality control the end products are less likely to make it to premium markets where they can be sold at a price high enough to justify investments in local processing equipment.
- **If not already present, initiating local cashew processing requires an expert operator and/or significant capacity building.**
- **Commercial cashew processing businesses processing a minimum scale of ~1.5 tons of raw nuts per day would utilize at least some equipment that can be mini-grid-powered.** However, from the data collected in this study, it is unclear how often mini-grid-suitable communities will be situated near cashew supply chains that can satisfy the volume requirements of mechanized cashew processing.

A.8.1 Crop Background and Market Characteristics

Cashew nuts are kidney-shaped drupes which grow on the ends of cashew apples — the edible fruits of cashew trees. The prime target of cashew cultivation are the kernels, which are misnomered "nuts" by consumers. These kernels comprise just 30% of raw cashew nuts' weight, and many processing steps are required before kernels are sold to final consumers.[121]

The edible cashew kernel is guarded by a shell, a "testa" (peel), and a corrosive oil called "cashew nut shell liquid" (CNSL). For the industrial processor, CNSL is a valuable side-product with industrial applications. But local cashew shellers cannot collect CNSL without specialized equipment. For manual processors, CNSL is a workplace hazard: an irritant that elicits a poison-ivy-like reaction on exposed skin during shell removal.[122]

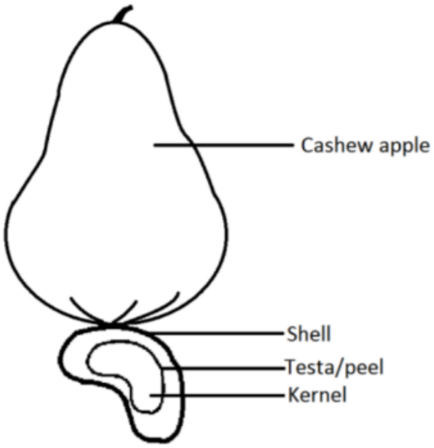


Diagram of cashew apple and cashew nut, excerpted from Reitsma, 2017.[115]

Although cashew apples are edible, only roughly 5–8% of these fruits are utilized, in part because the fruit ripens before the nut.[123] It is still possible to use the overripe apples for secondary products, but most cashew farmers toss them aside as waste.[124] In 2015–2016, the Cashew Byproducts Project equipped 85 women to process this feedstock into honey, cashew cake, and other products.[125] This intervention succeeded in empowering participants and raising incomes. However, this proof-of-concept has yet to scale across Nigeria and doing so would require significant development support. Therefore, we focus our analysis on the processing of raw cashew nuts to salable kernels.

Cashew grows over most Nigerian agroecological zones but does best in humid and semi-humid regions **(Figure 4**). However, cashew was not common in the communities we surveyed: 0 and 13% of communities in Kaduna and Cross River, respectively, were reported to have more than five cashew producers.

[I] For those interested in investing in local cashew processing, the GIZ's Competitive Cashew Initiative has published a set of practical guides to the process, the business opportunity, and equipment procurement which are available at https://www.comcashew.org/downloads .

Cashew trees start bearing fruit two to four years after planting and continue for 25–30 years after.[125] 70–90% of Nigerian cashews are grown by smallholders who cultivate unimproved varieties of trees under rainfed conditions.[124] Reported cashew yields range widely with tree planting density and other factors but are generally low: 500 kg/ha in Nigeria versus 1,500 kg/ha in Tanzania.[126] Unlike annual crops such as maize or rice, there are limited options for dramatically increasing cashew tree nut yields from year to year (especially for aging tree stands). Improving yields is a long-term play requiring introduction of new trees of improved varieties, optimal spacing and plot preparation, irrigation systems in water-stressed environments, and other practices that ensure the health of a plantation over the trees' lifetimes.[127,128]

Cashew is a seasonal crop that is harvested in February–May annually but if well-dried it can be stored and processed steadily throughout the year.[126]

Approximately 60% of the value add between freshly harvested raw nuts and cashew kernels occurs beyond the farm gate.[126] West African nations account for 43% of global supply of raw nuts but lag processing powerhouses India and Vietnam who perform kernel extraction for 92% of global raw cashew nuts.[129] Only 5–10% of Nigerian cashew nuts are processed to kernels domestically — the rest are exported as whole, raw nuts.[128]

Cashew apple (yellow) with attached nut (green).[li]

In Nigeria, locally-processed kernels may not reach international markets but can reportedly sell at a higher price than that received from raw nuts destined for export.[126] Kernels that pass quality standards and reach international markets may receive an additional 50–100% price premium compared to selling in local markets.[124]

Small-scale processors selling to local consumers tend to have very low daily throughput and most still use manual methods: one study of 72 small Nigerian processors found that 96% of these businesses processed less than 15 kg of raw nuts per day.[130] These study respondents cited a lack of capital to purchase improved equipment as the key constraint for their businesses, though it is unlikely that mechanization is profitable for these businesses without increasing throughput by two orders of magnitude (**Appendix A.8.3**, below). Local processors must also compete for access to raw cashew nuts with

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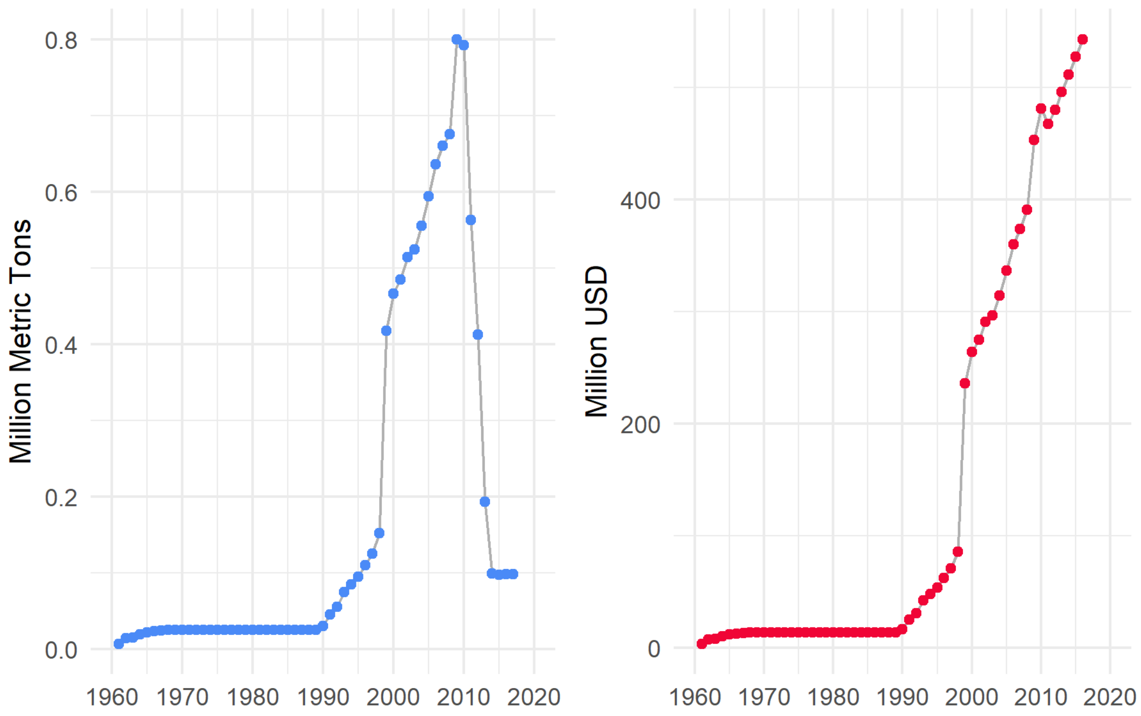
[li] Ripe Cashew Apples by Abhishek Jacob is licensed under CC BY-SA 3.0.

preexisting nut export value chains. Building commercial-scale cashew processing factories that can play in international export markets takes specialized expertise, equipment, and significant start-up capital.

On the export market, cashew kernel prices are graded stringently on quality, with the benchmark grade (W320, whole white kernels giving 320 kernels per pound) fetching more than twice the sale price of the lowest quality kernel pieces.[124] One ton of raw cashew nuts yields ~200 kg of decorticated kernels at varying quality grades (including pieces and whole kernels), although kernel recovery can be higher (~400 kg) in other countries.[124,126] The proportion of decorticated kernels at high quality grades depends on the skill of the operator: in practice whole kernel yields range from 55–85% of theoretical.

Figure 37: Gross National Production (Left) and Gross Value (Right) of Raw Cashew Nuts In Nigeria[10]



FAOSTAT figures show production to be growing through the 1990s and 2000s, with a sharp downward turn in 2011. This is likely a correction of previously mis-reported data on production, rather than an actual decline from ~800,000 metric tons per year reported in 2009 and 2010 statistics. Côte d'Ivoire, widely considered the world's leading cashew producer, only reported 700,000 metric tons of production in those same years. These series demonstrate the lack of quality data available on Nigerian cashew.

World cashew kernel consumption continues to grow at 7–10% annually, putting producing countries such as Nigeria in a favorable position to fill demand.[131] We note that data on Nigerian cashew producers and processors was especially scarce at the time of this writing (**Figure 39).** Future readers may benefit from to-be-published materials from PRO-Cashew, a United States Department of Agriculture project working to improve cashew production and markets throughout West Africa from 2020–2025.[lii]

[lii] Implemented by CNFA.

A.8.1.1 POST-HARVEST LOSSES

Upon arriving in Lagos for export, up to 20% of a shipment may be rejected for moisture content, nut breakage, and other quality metrics.[126] Uneven application of quality control criteria at the local level may apply some perverse incentives through the value chain: partially dry nuts weigh more per unit volume (to the benefit of the farmer who is selling) but incompletely dried nuts may mold during storage and shipping. [124] Inadvertent post-harvest losses also come from "impatient harvesting" practices, in which immature nuts are removed from trees too early, sometimes before kernel formation has completed. Some producers were found to have lost up to 25% of their harvest from these practices.[126] Kernel quality can also be degraded by discoloration (if left on the ground too long before collection) or pest damage.[132]

This quality degradation manifests as post-harvest value lost along the cashew value chain. Assessing the quality of raw cashew nuts is a complex task, but one that must occur throughout the supply chain (i.e., by farmers, local buyers and middlemen, processors and exporters) to ensure fair prices throughout.[132] In the past, Nigerian cashew has struggled to keep up with the quality offered by other suppliers, sometimes discounting Nigerian exports by up to 30% compared to African competitors on the export market. [126]

A.8.2 Value Chain Description

In the communities we surveyed, the data suggest that most farmers sell whole, raw cashews without further processing. In this case, the post-harvest process within the mini-grid community entails harvesting the fruits, separating the nuts from the apples, drying for 3 to 5 days (from 25 to 7–8% moisture content), and then selling on to local traders or buyers representing local processors.[124]

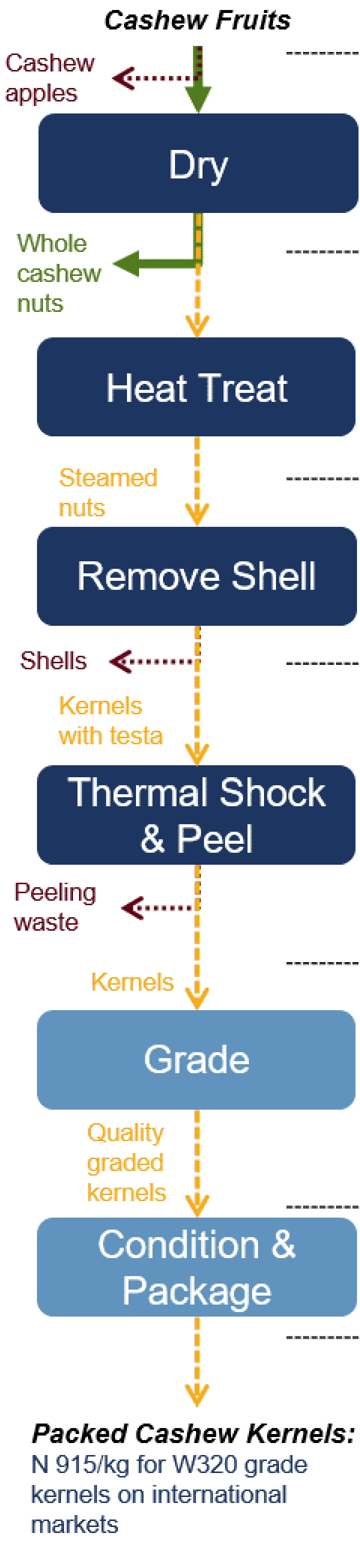
Significant processing is required before cashews can be consumed as kernels, i.e., the form familiar to consumers. This process is specialized and, contrary to processing of almonds or groundnuts, cannot be performed by an average household.[124] **Figure 38** describes each step in cashew kernel production along with opportunities for mechanization.

As noted above, the market value of the resulting kernels is contingent upon the skill of the process operator, the quality of the input cashew nuts, and the sensitivity of the market to quality. Without further in-country study it is difficult to determine the degree to which these necessary ingredients are found in mini-grid-suitable communities.

High quality cashew kernels ready for sale.[liii]

[liii] Photo by Maja Vujic on Unsplash

Figure 38: Unit Operations in the Cashew Value Chain.



	Description	***Mechanization***
Dry	Cashew farmers dry whole nuts before sale at the farm gate. Most farmers do not perform processing beyond this step.	Sun drying is predominant, if not exclusive, practice in Nigeria.
Heat Treat	Nuts are soaked in water and then steamed to enable shell removal. The steam & cut method is dominant in West African processing businesses.	In small batches, whole nuts are boiled in a pot over a traditional cooking fire. Larger operations use specialized boilers heated by biomass or fossil fuels.
Remove Shell	Remove the shell to obtain the kernel.	There are manual, semi-mechanized and fully automatic shelling methods. Selection depends mostly on scale of processing operation.
Thermal Shock & Peel	A thermal shock is applied prior to removal of the testa ('inner skin'). Best results are achieved by oven drying, humidifying, and then drying once more. The shock reduces adhesion of testa to kernel.	Ovens and humidifiers required for optimal thermal shock. Testa removal is typically done manually with a paring knife. Peeling machines can speed the process but are typically followed by a quicker hand-peeling step.
Grade	The nuts may be graded before sale to allow larger or more intact kernels to be sold at a higher price than smaller kernels or loose pieces. Color is also a factor.	Mechanized graders use sieves to sort kernels and pieces by size. Larger operations may sort mechanically by color, but color grading is performed manually at medium scale and below.
Condition & Package	Condition kernels to 3.5–4% moisture and vacuum pack.	Humidifier or dryer to reach precise moisture content. Vacuum sealer and packaging.

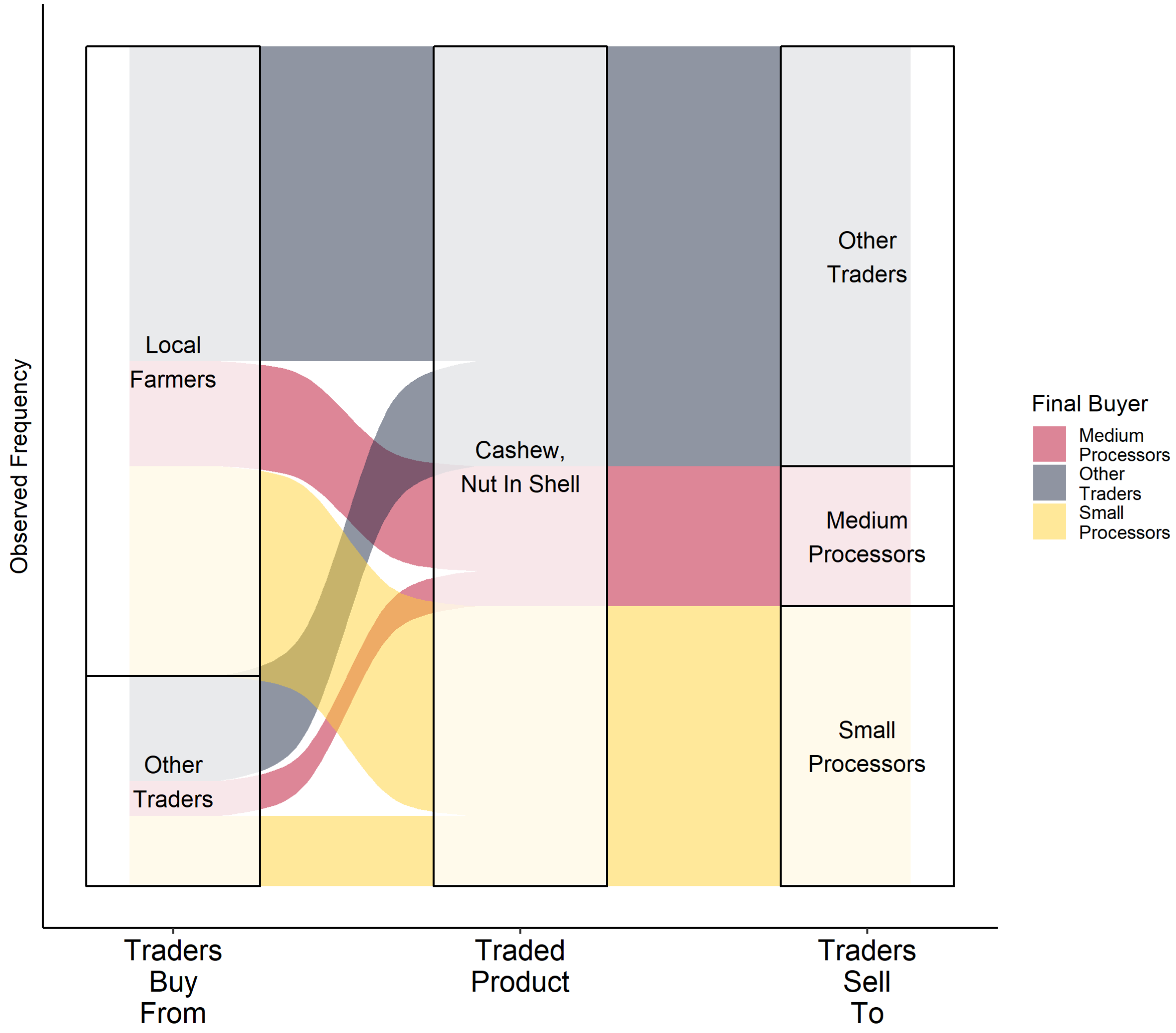
Mass Flows		Process Steps
🟩	Primary Activity	Required
▪▪▪	Secondary Activity	Optional
▪▪▪	Waste Stream	

Most nuts are sold whole to traders and exported. The remaining process steps describe operations for a medium-scale cashew nut processing facility typically not found in mini-grid communities

A.8.2.1 LOCAL TRADE

Most cashews leave Nigeria as dried whole nuts without any significant processing. Some cashews are retained in the community for local consumption and are processed by low-volume traditional processors. Local buying agents may represent small- or even medium-scale processors **(Figure 39)**, although none of these commercial processors were located in the communities we surveyed .[126]

Figure 39: Frequency of Local Trade Flows for Cashew in Surveyed Communities.



Flow size is proportional to the likelihood of the trade from source to final buyer.

A.8.3 Opportunities for Electrification in Cashew Kernel Production

Mechanical cashew processing is complex, involving many steps, and potentially several different pieces of equipment, as summarized in **Figure 38**. At the resolution of data available in our survey and the literature review, it appears unlikely that any of these processes are prevalently mechanized in off-grid Nigeria. Equipment begins to become economically feasible at throughputs designated in tons-per-day. In addition, due to the fragility of the kernel, it is not possible to partially process in mini-grid communities and then transport kernels in bulk to a larger specialized processor for finishing. Thus, we evaluate the opportunity to electrify the process as a whole, and we classify the opportunity as Tier 3.

TIER 3

Mechanized Cashew Kernel Production

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Mechanized cashew processing is highly complex and requires investment in a small factory to effectively mechanize. If these cashew processors are not already operating in the community, significant capacity building or an expert from outside the community will be required to successful operate a kernel production facility.
Offtake Market	◔	The cashew kernel offtake market is highly selective, applying detailed international quality standards to each purchase. These buyers do not already visit cashew-producing communities.
Electric Equipment	◑	Electric equipment is available for a variety of unit operations but requires ton-per-day minimum scales to be financially feasible.
Scalability	◑	Domestic cashew kernel processors will need to compete for supply with a robust export market for raw nuts that offtakes 90% of production today. It is unclear how many mini-grid-suitable communities will possess both the expertise for cashew kernel production and access to adequate supply for mechanized processing. However, in the long term there is significant potential to improve the value add of Nigerian cashew sector through increased processing capacity.

The objective of cashew processing is to efficiently remove the fragile kernel from the nut while maintaining taste and color, as well as minimizing kernel breakage. The labor-intensive process requires careful execution of a complex series of steps and, if mechanized, the correct selection of equipment and equipment operating procedures. [133]

In manual processing operations, heating, shelling, peeling, and sorting are done by hand, processing <10 kg of kernels per worker per day.[129] Mechanized processing begins to be profitable at a minimum scale around ~1.5–3 tons of raw nuts per day, and thus we focus this section on these commercial operations.[134] In mechanized processing shelling, peeling, and grading can be done more quickly using specialized pieces of equipment. All cashew processing below fully automated factories (>10,000 tons/year) still requires a significant number of skilled workers to run machinery, perform some manual processing, and transport material between unit operations.[134]

Steaming: Heat-treating whole nuts

The smallest cashew boilers have capacities of 2–2.5 tons/day and steam is nearly always generated through combustion of biomass or fossil fuel. Electric boilers are available but heating these devices with mini-grid electricity is very unlikely to be economically feasible (see **Box A.4 in Section A.4.3**).

Shelling: Extracting the Kernel

Manual shelling is traditionally performed by striking the nuts with a mallet or baton. This is expectedly slow work: experienced manual shellers produce around 5 kg of kernels per day.[122] For more efficient small-scale processors, lever-action manual nut cracking tools have improved the shelling process tremendously over traditional methods. Manual and semi-manual shelling expose the participants to CNSL, posing a workplace hazard for processors, who are predominately women.

Fully automatic shelling machines mechanically de-shell 80–90% of nuts fed while minimizing kernel damage. These machines can be electric. Mechanized shelling begins to be profitable around ~1.5 tons/day of raw nut throughput, as standalone low capacity shelling machines are utilized in factories with capacities as low as 500 metric tons per year.[134] Automatic shellers that are improperly calibrated or in disrepair may produce high proportions of broken kernels – careful supervision is required to ensure quality. In India, some cashew shells are sold to buyers who process them for CNSL or heating briquettes for an additional $150/ton. [131] The shells can also be used as fuel for the steaming and heat shocking processes in this value chain.

Pre-Peeling: Heat Shocking the Testa

Shelled nuts are heated in temperature-controlled ovens to weaken the testa prior to peeling. Because these heating ovens do not need to supply the tremendous amount of energy required to boil water (as in the steaming step), they can plausibly be served by mini-grid electricity in addition to biomass or fossil fuels.[134] Even drying is important to ensure a uniform heat treatment..

Peeling: Removing the Testa from the Kernel

A person peeling by hand can process 10–12 kg of kernels per day.[122] Peeling machines use compressed air to separate the testa from the kernel before a manual peeling step, reducing manual peeling labor by 60–80%.[134] Small-scale peeling machines start at 50–60 kg/hour. A 2018 expert panel selected peeling as the top priority step for mechanization in cashew kernel processing.[134] Careful calibration and maintenance of these devices is required to prevent damage to kernels.

Grading: Sorting by Color and Size

Simple grading machines use sieves to separate whole from broken kernels and are suitable for smaller scale processors. Large commercial operations may use sorting machines to grade nuts by color and size, but these are not feasible in small and medium processing facilities.[134]

Packaging: Cleaning and Vacuum Sealing

If nuts were to be processed into kernels at the local level for outside sale, specialized packaging practices must be adopted to protect the fragile kernel.[124] These include cleaning the kernels (with an aspirator) and vacuum sealing in carbon dioxide (with a vacuum sealer, vibrating filler, and CO_2 source). Depending on the buyer, kernel processors need to conform to one of three marquee quality standards: Association of Food Industries standards for the American market, the Cashew Export Promotion Council of India standard, or the United Nations Economic Commission for Europe standard for the European market.[133] Vacuum packing machines exist at a variety of scales, but all require electricity. [134]

Setting up the business

12–18 months of planning, procurement and installation are required to start a processing operation for 5,000 metric tons of raw nuts per year.[131] Payback periods for successful operations of this scale are on the order of 3–5 years.

In the past ten years, suppliers for cashew processing equipment have improved performance and diversified geographically. In 2011, the only appropriate equipment for small- and medium-sized cashew nut processors were built in Vietnam. Now, buyers with access to international markets can choose from numerous manufacturers in Asia, Brazil, North America, and even Nigeria itself.[134] With the diversity of equipment options comes a dizzying array of options to a new cashew processor. According to the GIZ's Guidebook for Cashew Nut Processing Equipment, "*…buying cashew-processing equipment has never been more complex or demanding. Getting the decision right or wrong can have long term implications for the success or failure of the business (pg. 9).*" [134]

A.9 *Cowpea*

- **Cowpeas are nutritionally important.** Legumes account for 17% of protein intake in Nigeria, with 61% coming from cowpeas.
- **Cowpeas are often grown, processed, and consumed within the community.** Popular foods such as *akara* require significant number of processing steps and are predominately made in small batches by women sellers.
- **Cowpea milling is a Tier 1 opportunity for electrification with mini-grids.** Other processing steps such as dehulling and threshing could be electrified but the demand for mechanization of these processes is less certain.

A.9.1 Crop Background and Market Characteristics

Cowpeas are an exceptionally drought-tolerant, nutritious grain legume prevalent in Sahelian states. The plant typically grows as a short row crop up to one meter tall, and cowpea grains develop in long pods containing 6–13 seeds each (see photo).[135] Its long taproot and wide spread make it especially good at preventing erosion and suppressing weeds. Cowpea is leguminous, meaning it uses symbiosis with bacterial colonies to pull nutritious nitrogen directly from the air. This reduces the need for nitrogen fertilizers and improves soil health for other crops that may be planted later.[136] Known as the "black-eyed pea" in the United States, the crop's versatility made it one of few species NASA selected for study for cultivation in space stations.[137]

Because of these agronomic qualities, cowpea is prevalently cultivated in Northern Nigerian states: 60% of surveyed communities in Kaduna cultivated cowpea, compared to 20% of communities in Cross River. It is commonly intercropped with sorghum, millet, maize, cotton, or cassava. [137]

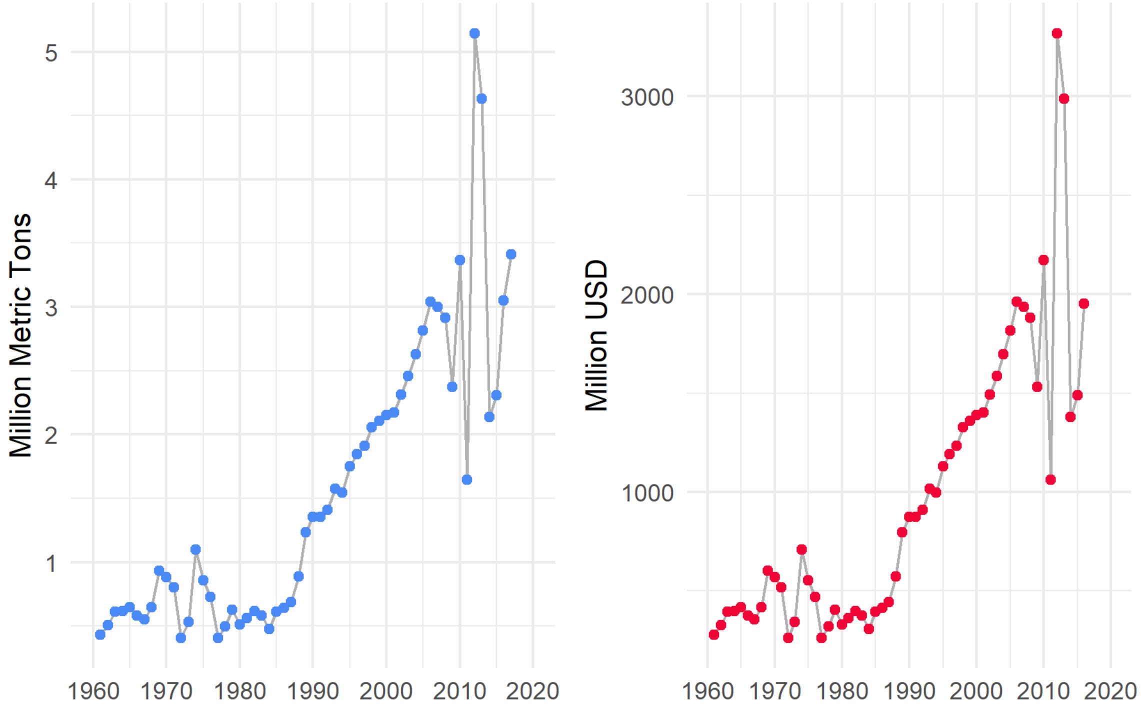
Harvested cowpea pods in Damaski community, Kaduna state. This community of 300 households primarily farms maize, sorghum, cowpea, and chili peppers.

Cowpea grain yields in our survey ranged from 400–1,000 kg/ha compared to 1,600 kg/ha for improved Nigerian varieties, and 4,000 kg/ha for top producers in other countries.[137–139] Adoption of improved cowpea seed has been estimated at 10–30% of planted area.[138] Cowpea yields suffer from parasitic weeds (genus *Striga*), which infest cereals throughout semi-arid West Africa and out-compete the crop for resources.[140] No single method can eliminate *Striga* but weed management can be combined with improved plant varieties that offer resilience to pests and drought.[139] Insect damage can occur during crop growth or post-harvest storage, though the problem is solvable with integrated pest management and proper storage. Irrigation can provide yield boosts over rainfed production but remains uncommon for most producers. One study of Bauchi and Kano states found that just 15% of cowpea and maize farmers interviewed had access to irrigation equipment.[140]

Cowpea grains (simply 'beans' in Southern states) can be consumed as whole beans, paste, or flour and are a major source of affordable protein for households that cannot afford meat or fish.[141] Legumes account for 17% of protein intake in Nigeria, 61% of which comes from cowpeas.[142] The seeds are rich in protein and fiber, making them a valuable component of smallholder diets.[143] In one study of 150 households in Niger state, cowpeas displayed price inelastic demand for cowpeas, again showing their importance to local consumption.[141]

Nigeria is the world's largest cowpea producer and consumer, generating roughly 3 million metric tons per year and consuming 2.2 million metric tons per year (**Figure 40**).[139] Nigerians also lead in per-capita consumption, at 18 kg/person/year versus 9 kg/person/year in Ghana, the country with the next-highest rate.[138] A network of traders supports the movement of cowpea from rural production areas, to regional markets, and then onto urban consumers.

Figure 40: Gross National Production (Left) and Gross Value (Right) of Cowpeas In Nigeria[10]



Local small-scale processors often make and sell small batches of *Akara* — a popular fried snack made by frying cowpea paste — and *Moinmoin*, a steamed cowpea pudding.[144] One study estimates that 15–20% of Nigerian cowpea production is processed, marketed, and sold as informal processed foods, at a market value around $850 million dollars.[138] Another estimate suggests that 50% of cowpea production is sold by farmers into the domestic food market, much of which is then processed by local plate mills.[138] These small businesses tend to process much higher volumes than those in neighboring countries: the *akara* vendors in southern Nigeria are reported to triple the throughput of similar businesses in Niger.[145] These informal processors are mostly women. [142]

A.9.1.1 POST-HARVEST LOSSES

Properly stored, cowpea grains or flour can last many months before processing, consumption, or sale. Farmers surveyed indicated very low levels of postharvest losses – around 3% on average. Insect damage is a major concern, with pests such as the cowpea seed beetle claiming up to 80% of stored beans if undetected and unmitigated (15% average losses).[146] Commercially-available hermetic storage bags cut off oxygen supply for insects that may be present in stored grain, effectively halting their growth for as long as the container remains airtight.[147] A 2010–2011 study found that about two-thirds of Nigerian cowpea farmers have adopted hermetic containers, with about 50% utilizing the maximally-effective triple-layer bag.[148] The same study finds that improved market access to triple-layer bags increases cowpea farmer incomes. Thus, no major post-harvest losses are identified that may be solved with electricity access.

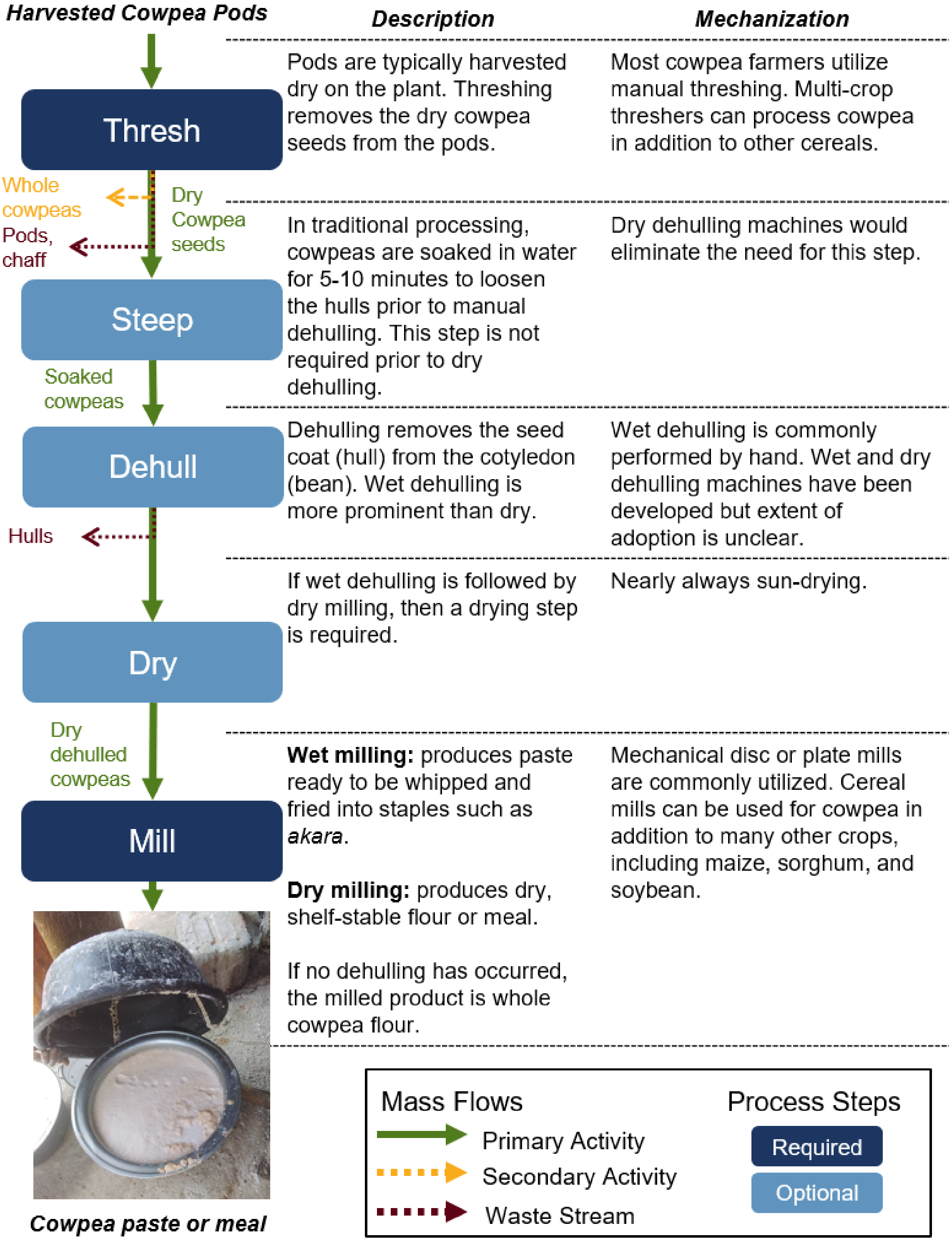
Once processed into a paste, the high moisture and fat content of cowpea dishes renders them shelf stable for ~24 hours.[143] Refrigeration at the consumer level may reduce spoilage at home.

Garba Mohammed farms cowpea, maize, and chili peppers in Garmadi community, Kaduna state. From his irrigated fields, he harvests and sun-dries ten 100kg bags of cowpea per season and reserves two of them for his household's consumption. Mr. Mohammed does not recall losing cowpeas to spoilage very often.

A.9.2 Value Chain Description

Cowpea is a versatile crop that can be processed into a variety of dishes. Threshed cowpeas can be soaked and cooked whole or processed into flours and meals. [149] We focus our value chain analysis on the process of making milled pastes or meals from harvested beans because it includes many of the steps shared by other cowpea-based products. Processing steps include threshing, soaking, hull removal, drying, and milling, as described in **Figure 41**.[138]

Figure 41: Value Chain Steps from Harvested Cowpea Pods to Milled Cowpea Paste

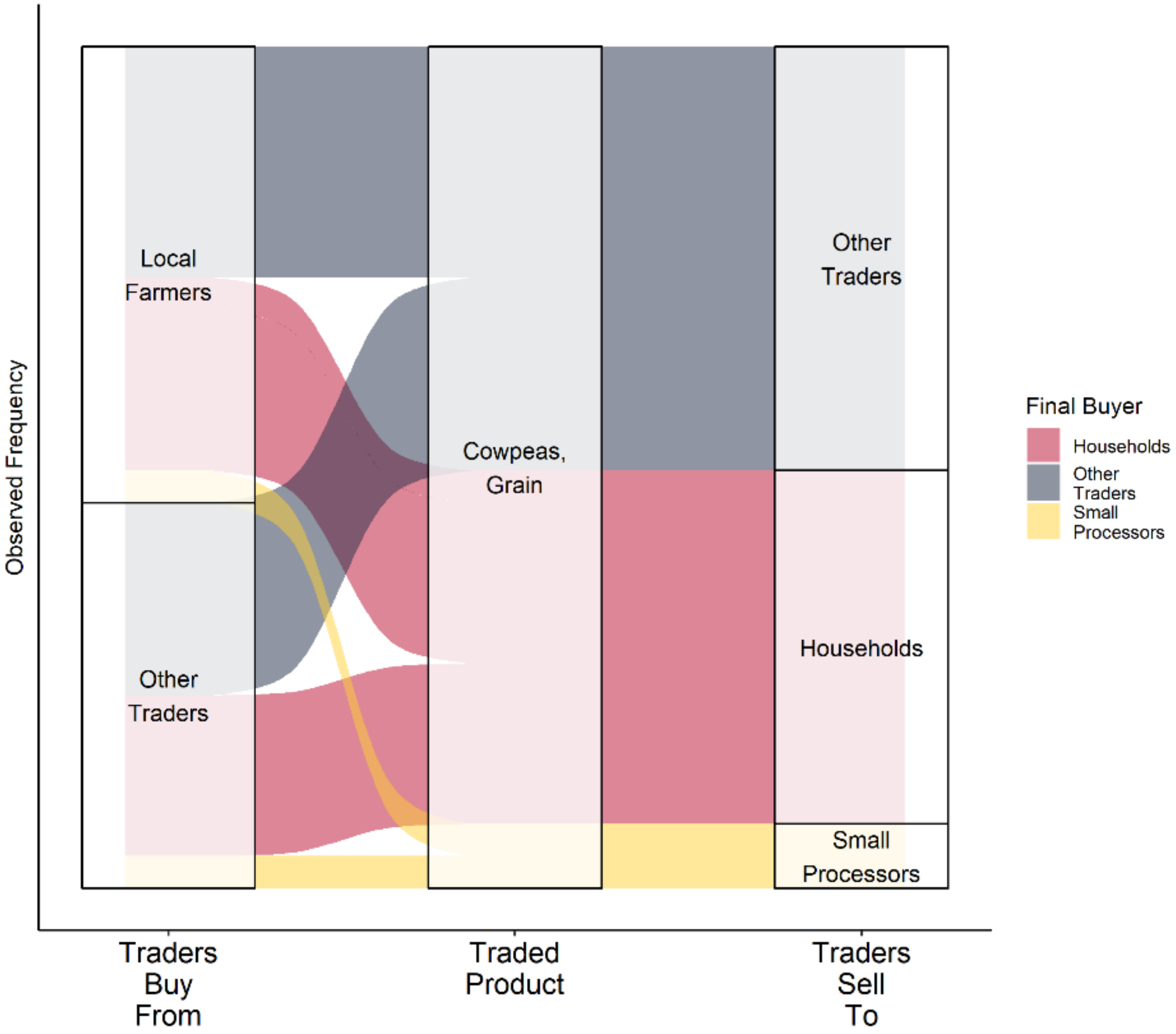


	Description	***Mechanization***
Thresh	Pods are typically harvested dry on the plant. Threshing removes the dry cowpea seeds from the pods.	Most cowpea farmers utilize manual threshing. Multi-crop threshers can process cowpea in addition to other cereals.
Steep	In traditional processing, cowpeas are soaked in water for 5-10 minutes to loosen the hulls prior to manual dehulling. This step is not required prior to dry dehulling.	Dry dehulling machines would eliminate the need for this step.
Dehull	Dehulling removes the seed coat (hull) from the cotyledon (bean). Wet dehulling is more prominent than dry.	Wet dehulling is commonly performed by hand. Wet and dry dehulling machines have been developed but extent of adoption is unclear.
Dry	If wet dehulling is followed by dry milling, then a drying step is required.	Nearly always sun-drying.
Mill	**Wet milling:** produces paste ready to be whipped and fried into staples such as *akara*. **Dry milling:** produces dry, shelf-stable flour or meal. If no dehulling has occurred, the milled product is whole cowpea flour.	Mechanical disc or plate mills are commonly utilized. Cereal mills can be used for cowpea in addition to many other crops, including maize, sorghum, and soybean.

A.9.2.1 LOCAL COWPEA TRADE

Cowpea trade flows exhibit strong local market demand (**Figure 42).** They are typically traded as dry beans before dehulling or milling. Many households purchase cowpeas for home consumption and utilize local fee-for-service mills to produce flours or pastes. Cowpea famers in our field survey consumed an average of 20% of their primary cowpea production. Local traders move about 50% of production on to other markets beyond the community.[138]

Figure 42: Frequency of Local Trade Flows for Cowpeas in Surveyed Communities



Flow size is proportional to the likelihood of the trade from source to final buyer.

A.9.3 Opportunities for Electrification in Cowpea Processing

Analyzing key considerations for cowpea flour production activities finds Tier 1 (wet and dry cowpea milling), Tier 2 (threshing), and Tier 3 (mechanical grain drying) opportunities. These opportunities are similar across other cereals in the study including maize, sorghum, and soybean.

Cowpea Milling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	●	Cowpeas are already mechanically processed at the local level to produce common foods.
Offtake Market	●	National data and local trade flows show strong market for products of cowpea.
Electric Equipment	●	Cowpeas can be milled with mill utilized for other cereals, which are commonly electrified. Existing fossil-fueled mills may be retrofitted.
Scalability	●	Nigeria has the largest cowpea consumer base in the world, and cowpea production and processing is dispersed geographically across the country.

Cowpeas can be dry or wet milled, depending on the intended final product. In wet milling, soaked, dehulled cowpea seeds are processed into a paste that is ready for use in popular dishes such as *akara.*[150] Dry milling processes dry cowpea seeds into a shelf-stable flour or meal. The consistency of the milled cowpea products is very important to consumers: intermediate particle size between fine flour and coarse grits is required for the hydration characteristics typical of good-quality *akara.* [151,152] Dry milling is more energy efficient than the wet milling process, but consumer preferences will dictate which technique is utilized.[151]

Cowpea flour and meal milling is often mechanized in mini-grid-suitable communities, although some smallholders still manually process cowpeas for home consumption. In our field survey, mechanical mill operators who processed cowpea typically reported processing some combination of soybean, sorghum, and maize grain with the same device. A 2016 Feed the Future study recommended increasing women's access to grinding machines as a key component of a cowpea development program.[145]

Cowpeas can be ground with cereal mills, although some fee-for-service millers will refuse to mill cowpeas because they can leave a "beany odor" and residue on the mill that will be noticeable in other mill products.[143] Mills can be rid of these odors if thoroughly cleaned, although many processors then charge a cleaning fee to cover these costs.

Cowpea milling is a Tier I opportunity for electrification with mini-grids. Wet or dry milling of cowpeas can improve the capacity utilization of multipurpose cereal mills used to process other crops, although careful attention to customer preferences for consistency and flavor must be considered when selecting equipment for pilot projects.

Ayuba Tasiu's 5.5 horsepower petrol grinder for wet milling cowpeas in Anguwan Malam Dogo, Kaduna state. Mr. Tasiu uses the same mill for making soybean flour.

Cowpea Threshing

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◑	Cowpeas must be threshed and are more suitable for a stationary thresher than other crops (e.g., rice). However, mechanical threshing of cowpea is less common than for maize and the business case for an electric multi-crop thresher has not yet been proven to be competitive with local manual threshing labor costs.
Offtake Market	●	Local traders, households and processors provide a strong market within mini-grid-suitable communities.
Electric Equipment	◕	Electric threshers are available in Nigeria, and old threshers can be retrofit with new electric motors.
Scalability	◕	Nearly all cowpeas are shelled from the pod before sale or processing, and all cowpea farmers report interest in a mechanical threshing option for the right price.

Only 20% of cowpea farmers in our field surveys utilized mechanical threshing. Most farmers pay for threshing either to hire manual labor or for fee-for-service mechanical threshing, spending 300–15,000 Naira per harvest of 300–7,000 kilograms of cowpeas. 100% of farmers “strongly agree” that they would be willing to transport harvested cowpeas from the field to be threshed. This is much stronger confirmation of interest in mechanical threshing than received for rice, matching the level of interest observed for maize.

The Feed the Future Soybean Innovation Lab has sponsored development of a multipurpose thresher that is suitable for maize, soybean, rice, sorghum, cowpea and common beans.[153] This multi-crop thresher is 80% faster than manual threshing and reduces postharvest losses by 35%.[8] Other Nigerian equipment manufacturers offer threshers that are compatible across crops.[154] However, the business case for a multi-crop thresher, including its use for cowpea threshing, is difficult to make at the pre-pilot stage. The case for multi-crop threshing devices is discussed further in **Appendix A.1.1.**

Because the viability of the mechanized threshing business model is tenuous until pilot tests are conducted, we rate cowpea threshing as a Tier 2 activity.

TIER 3

Cowpea Drying

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Nearly all cowpea is sun-dried. Introduction of a mechanical option would require capacity building.
Offtake Market	◑	Offtakers may offer higher prices for improved grain quality but markets are not sensitive enough to consistently value uniform moisture content. More industrial crops such as maize and soybean are more likely to achieve this market sensitivity before cowpea, which is less prominent in industrial processing.
Electric Equipment	◔	Mechanical grain dryers commonly use fossil fuel as a heat source. All-electric options are available but unlikely to be cost-effective at mini-grid tariffs
Scalability	◕	All cowpea grain is dried: an appropriate drying technology combined with a market to value precise moisture content control could achieve scale.

Cowpeas must be dried before threshing, and other drying steps may occur during processing, depending on the final product. However, since cowpeas are grown in more arid environments than some other cereal grains, 0% of farmers interviewed reported extensive issues with sun-drying their crops. It is unlikely that mechanical drying will make financial sense for the cowpea value chain in the near or medium term.

We classify cowpea drying as a Tier 3 activity following our ratings for Maize and Rice drying as presented in **Appendices A.3.3**, and **A.4.3**, respectively.

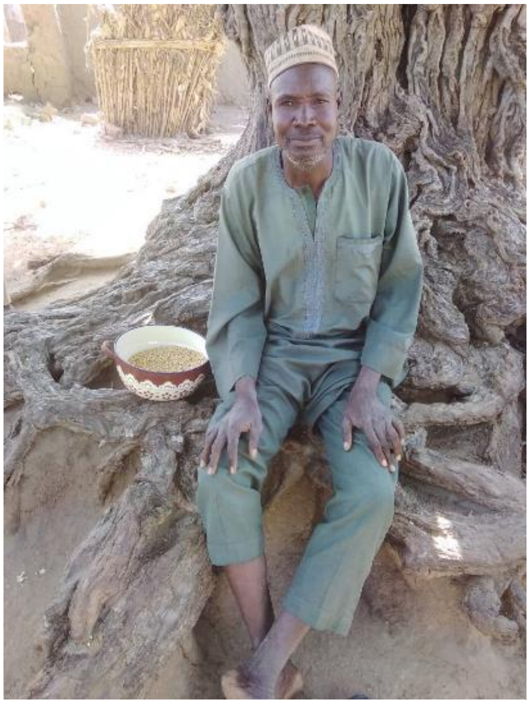
A.10 *Soybean*

- **Soybean is the industrially oriented cousin of cowpea in Nigeria.** Soybean is a grain legume in high demand by the feed and vegetable oil industry. It is consumed locally but is not a traditional staple food like cowpea.
- **Local soybean consumption is in competition with industrial offtakers** who are typically running large processing facilities at low capacity factors due to low supply.
- **Nearly 60% of soybean cultivation is concentrated among Kaduna, Kano, and Benue states.** This limits the scalability of soybean-specific productive uses. However, many process steps are similar those used for cowpea or other cereals.
- **At the local level, opportunities to mechanize soybean processing strongly resemble those for cowpea**

A.10.1 Crop Background and Market Characteristics

Soybeans are a highly versatile legume prized globally for their high protein and oil content. Agronomically, soybean is a hardy nitrogen-fixer that grows well under low agricultural inputs. When planted correctly short-duration soybean varieties can be grown even in arid Northern Nigeria.[155] Soybean is very commonly intercropped with maize, sorghum, or millet: the increased soil nitrogen from the legume benefits the other crop.[142]

Nigerian soybean yields have grown steadily over the past 30 years to one metric ton per hectare but still significantly lag South American (2.5–3 t/ha) and U.S. yields (4.5–5 t/ha).[156] Production is constrained by irregular rainfall (and lack of irrigation), as well as high seed prices for improved varieties and low availability of superphosphate fertilizer.[142] As for cowpea, *Striga* control is critical for optimal soybean yields.[155] The USAID Feed the Future Soybean Innovation Lab works to improve soybean production and utilization through research and development training.[liv]



Abdulkadir Aliyu posing with freshly threshed soybeans in Giwaye community, Kaduna state. Mr. Aliyu farms maize, soybean, and chili peppers near the town center. He uses mechanical threshing for maize but hires manual labor to thresh his soybean crop.

Soybean is more industrially oriented than cowpea. The growth of the poultry feed and vegetable oil sector has heightened demand for soybean's 40% protein content and 20% oil content.[9] After the seeds have been pressed for oil, the remaining protein-rich press cake is utilized for animal feed. The market for industrially processed soybean continues to grow rapidly, though industrial processing capacity has outpaced domestic growers' production. Most soybean processing facilities run at less than 50% of installed capacity.[9]

Soybeans' industrial utility motivates large offtakers to work with local smallholders to ensure and enhance domestic production. Olam, the largest buyer of Nigerian soybeans, is working to expand availability of "tropicalized" IITA seed varieties to farmers.[156]

At the community level, local processors and households transform soybeans into a variety of food products including flour, soy milk, baby food (i.e., 'Tom Brown'), cakes, porridges, fortified cereal staples

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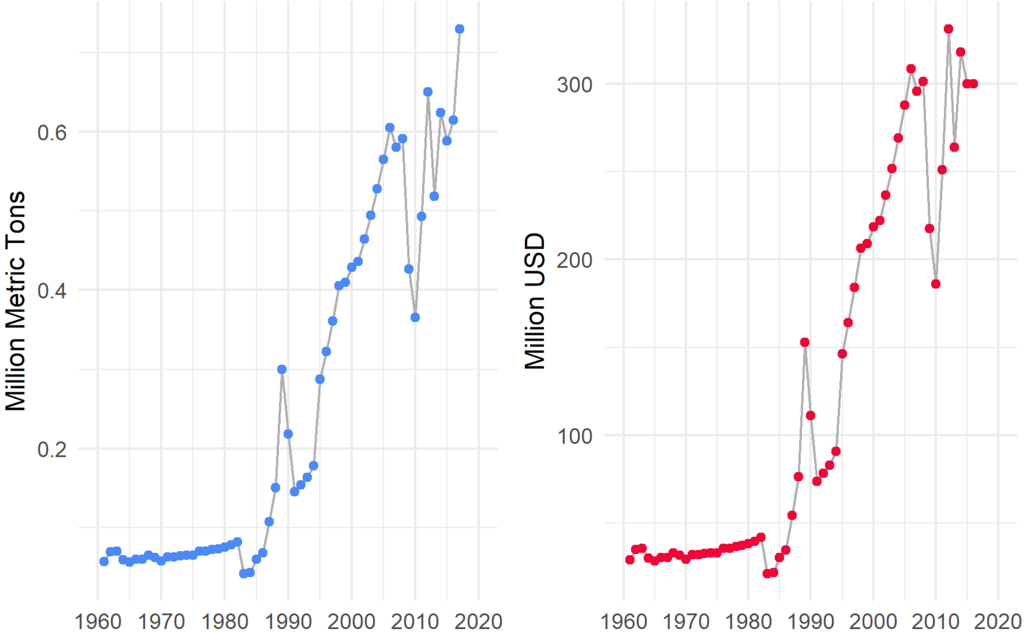
[liv] http://soybeaninnovationlab.illinois.edu/

(e.g., *gari*, *tuwo*, *pap*) and *wara* (a soy cheese).[9] The soybean farmers surveyed in this study consumed a median of just 10% of their production. Soybean is rarely eaten in whole bean form without processing.

Nigeria and South Africa are the largest producers of soybean in Africa, though total Sub-Saharan African production accounts for less than one percent of global production (**Figure 43**). Compared to cowpea, soybean is a relatively new entrant to Nigerian agriculture.[9] As a result, its cultivation is concentrated in a few emphasis areas: Kaduna, Kano and Benue states accounted for 12, 11 and 33% of soybean production circa 2012.[142] One in four communities we surveyed in both Cross River and Kaduna states were cultivating soybean as a major crop.

Figure 43: Gross National Production (Left) and Gross Value (Right) of Soybean In Nigeria[10]



A.10.1.1 POST-HARVEST LOSSES

Soybean should be stored at <10% moisture content to enable storage for >12 months. [155] At harvest, the grains contain about 14% moisture – a relatively small amount of drying is required to hit the optimal moisture content.[155] The same hermetic storage bags utilized for cowpeas are an effective means of reducing pest damage during storage. [146] Post-harvest losses resemble those observed for cowpeas, maize, and other similar cereals.

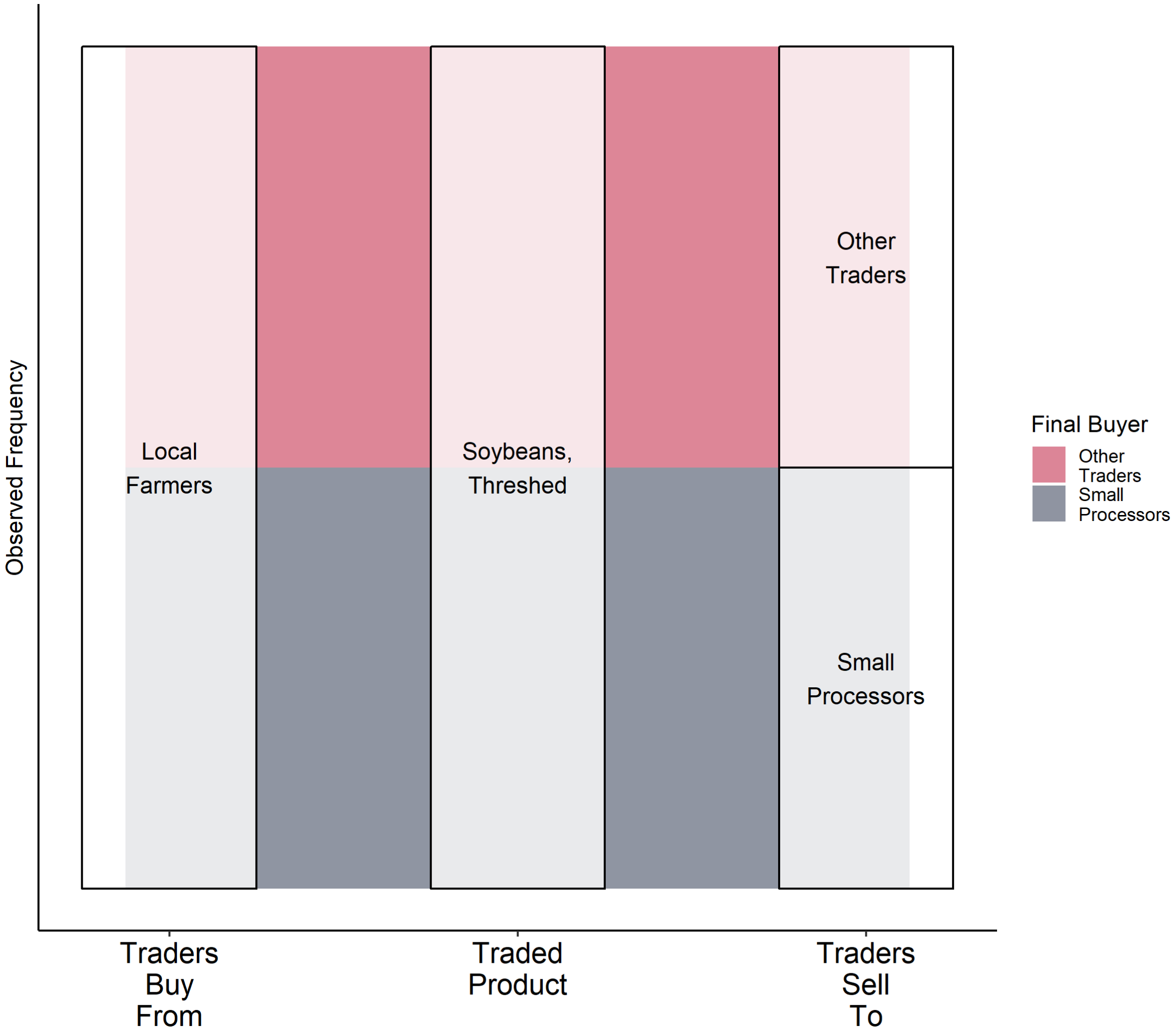
A.10.2 Value Chain Description

At the local level, soybean processing strongly resembles cowpea processing. The two grain legumes are physically very similar, and thus the process steps for transforming the seeds into a workable flour or paste are analogous.[lv] **Appendix A.9.2** and **Figure 41** describe these steps in further detail. Once soybean has been processed to this intermediate material, consumers or small businesses can go on to make soy milk, fortified versions of traditional cereal dishes (e.g., fortified *gari*, baby food), or cheese.[157] These final cooking steps do not have obvious mechanization potential, although basic refrigeration would extend the shelf life of processed soy products.

[lv] One notable difference between the two crops is that soybean is very rarely consumed as a whole bean, although total soybean consumption is much lower than total cowpea consumption.

A.10.2.1 LOCAL SOYBEAN TRADE

Figure 44: Frequency of Local Trade Flows for Soybeans in Surveyed Communities



Flow size is proportional to the likelihood of the trade from source to final buyer.

Compared to cowpeas (**Figure 42**), soybeans are more likely to be purchased and processed by local small businesses **(Figure 44**). This is likely because many soybean-specific foods (e.g., milk, cheese, fortified flours) require special cooking steps beyond the repertoire of the average consumer. A substantial portion of soybean products moves to industrial feed or vegetable oil operations via local traders.

A.10.3 Opportunities for Electrification in Soybean Value Chain

Analyzing key considerations for soybean flour production activities finds Tier 1 (wet and dry milling), Tier 2 (threshing), and Tier 3 (mechanical grain drying) opportunities. These opportunities are similar to those for cowpea, another grain legume (**Appendix A.9.3**) and so we provide abbreviated analyzes below.

Soybean Milling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◕	In communities where they are grown, soybeans are already mechanically processed at the local level to produce common foods.
Offtake Market	◕	National data shows a growing market for industrial soybean, and soybean-producing communities typically consume some locally processed products.
Electric Equipment	●	Soybeans can be milled with cereal mills, which are commonly electrified. Existing fossil-fueled mills may be retrofitted.
Scalability	◕	Soybeans are less extensively cultivated than similar crops in this study (e.g., cowpea, maize, rice, sorghum), but multi-crop mills can scale across all eligible crops.

Soybeans can be dry or wet milled, depending on the intended final product. The milling process for soybeans is nearly indistinguishable from that of cowpeas. Thus, we classify this activity as a Tier I opportunity and refer readers to our section on Cowpea Milling for further detail (**Appendix A.9.3**).

A flour mill in Dawan Malam community, Kaduna state powered by a 5.5 horsepower petrol motor. The Abdullahi family uses the same machine to offer fee-for-service milling for maize, soybean, and shea nuts.

TIER 2

Soybean Threshing

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◑	Soybean is not mechanically threshed in mini-grid-suitable communities today and potential customers express some skepticism regarding a centralized threshing model.
Offtake Market	◕	Local traders, households, and processors provide a strong market within mini-grid-suitable communities. Industrial demand for soybean may out-compete local demand in some cases.
Electric Equipment	◑	Electric threshers are available in Nigeria and old threshers can be retrofit with new electric motors. Further R&D would be required to produce mobile electric threshers.
Scalability	◑	All soybeans are shelled from the pod before sale or processing; however, soybeans are less extensively cultivated than other similar crops in this study (i.e. cowpea, maize, rice, sorghum, etc.)

Soybeans develop in pods, which are to be harvested when around 80–85% of pods have turned to a straw color.[155] After harvesting the full plant at ground level with a sickle or other cutting instrument, the plants are dried in the sun for ~2 weeks before threshing. Mechanical threshers can intake full dried plants and output soybean grains separately from the chaff.[153]

0% of farmers surveyed utilized mechanical threshing for their soybeans. Compared to cowpea and maize producers, soybean farmers tended to express more skepticism towards mechanical threshing in a centralized location. Rice farmers, too, were skeptical of this threshing model (**Appendix A.4.3**). The general pattern is that farmers are less inclined towards a centralized mechanical threshing model when their crop is harvested as a whole plant (e.g., soybeans, rice) compared to crops where it is possible to remove only the food-bearing portion (e.g., maize, sorghum, soybeans).

The viability of soybean threshing as a productive use opportunity depends upon farmers' willingness to transport their soybean harvest to a centralized location. An electric multi-crop thresher may achieve profitability by processing soybean in addition to other crops, but this business case has not been proven to be competitive with local manual threshing labor costs (**Appendix A.1.1**). Because customer acceptance and viability of the mechanized threshing business model is tenuous until pilot tests are conducted, we rate soybean threshing as a Tier 2 activity.

TIER 3

Soybean Drying

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◔	Virtually all Nigerian soybean is sun-dried. Introduction of a mechanical option would require capacity building.
Offtake Market	◑	Offtakers may offer higher prices for improved grain quality but markets are not sensitive enough to consistently value uniform moisture content. Industrial soybean offtakers may establish these quality standards with large aggregators, but it is unclear how this may translate to the community level in the short term.
Electric Equipment	◔	Mechanical grain dryers commonly use fossil fuel as a heat source. All-electric options are available but unlikely to be cost-competitive at mini-grid tariffs.
Scalability	◑	All soybeans are dried, but soybean cultivation is not as common as other crops.

Soybeans must be dried before threshing, and other drying steps may occur during processing, depending on the final product. However, since soybeans are grown in more arid environments than some other cereal grains, 0% of farmers interviewed reported issues with sun-drying their crops for more than one or two days per season. We classify soybean drying as a Tier 3 activity following our ratings for Maize, Rice, and Cowpea drying as presented in **Appendices A.3.3**, **A.4.3**, and **A.9.3**, respectively.

Lawisa Danjuma's freshly milled soybean paste in Takalafiya, Kaduna state. Mrs. Danjuma processes local soybeans into flour and paste using a fee-for-service model. She reports that business is steady through the year.

A.11 *Sorghum*

- **Sorghum is important to food security, especially in northern communities with limited land and water resources.**
- **Because it is often a crop of last resort, sorghum is more likely to be cultivated at low yields for human consumption than to be cultivated as a cash crop at large volume.**
- Sorghum can be threshed, winnowed, dehulled, and milled using maize-specific equipment.
- **If sorghum can be processed alongside other grains, it may improve capacity utilization of processing equipment.** But an investment with the express purpose of commercializing sorghum/millets is less likely to be financially viable because these crops are more often grown in smaller quantities for home consumption.

A.11.1 Crop Background and Market Characteristics

Sorghum and millets are drought-tolerant cereals that can be cultivated in harsh agricultural environments under low levels of inputs. Sorghum and millet are similar grain-bearing grasses but sorghum is the focus of this analysis.[158] Sorghum is most extensively grown in Northern states, where it is a significant contributor to smallholder livelihoods and accounts for an estimated 73% of total caloric intake. [159,160] The crop was cultivated by five or more farmers in 60% of communities surveyed in Kaduna but was not identified at any Cross River sites.

Yields are low, averaging one t/ha versus an average of 4.5 t/ha in the United States.[28,159] This is partly because sorghum is often grown as a 'crop of last resort' in rainfed marginal agricultural lands.[2] Suboptimal soils and moisture availability limit sorghum productivity, especially in semi-arid environments.[161] A survey of 226 farmers in Kwara state reported the following top barriers to sorghum production: inadequate access to improved seed, inadequate access to capital to improve their farms and buy inputs, and inadequate access to extension services.[162] Introduction of improved varieties combined with context-tailored fertilization has been modeled to raise theoretical yields to 7–8 t/ha in semi-arid areas of Kano, Sokoto, and Samaru states.[163] The Feed the Future Innovation Lab for Collaborative Research on Sorghum and Millet works to improve resilience and use of these crops in semi-arid African climates through genetic enhancement, production systems management, and added-value products. [lvi]

Shehu Idris, posing with dried sorghum stalks in Bature community, Kaduna state.

Sorghum is nearly always processed into a meal or flour before human consumption, with an estimated 80% of sorghum and millets milled into whole flour.[158,164] Milled grains are used to make traditional porridges such as *tuwo*, *ogi*, or *kamu,* in addition to deep fried snacks or steamed dumplings.[158] Some industrial processors offtake sorghum for use alongside maize in brewing or production of other processed foods. However, compared to maize, sorghum is much more likely to be self-consumed by farmers rather than marketed as a cash crop. [164] This tendency for self-consumption alongside especially poor supply chain connectivity in Northern communities makes the sorghum value chain particularly hard

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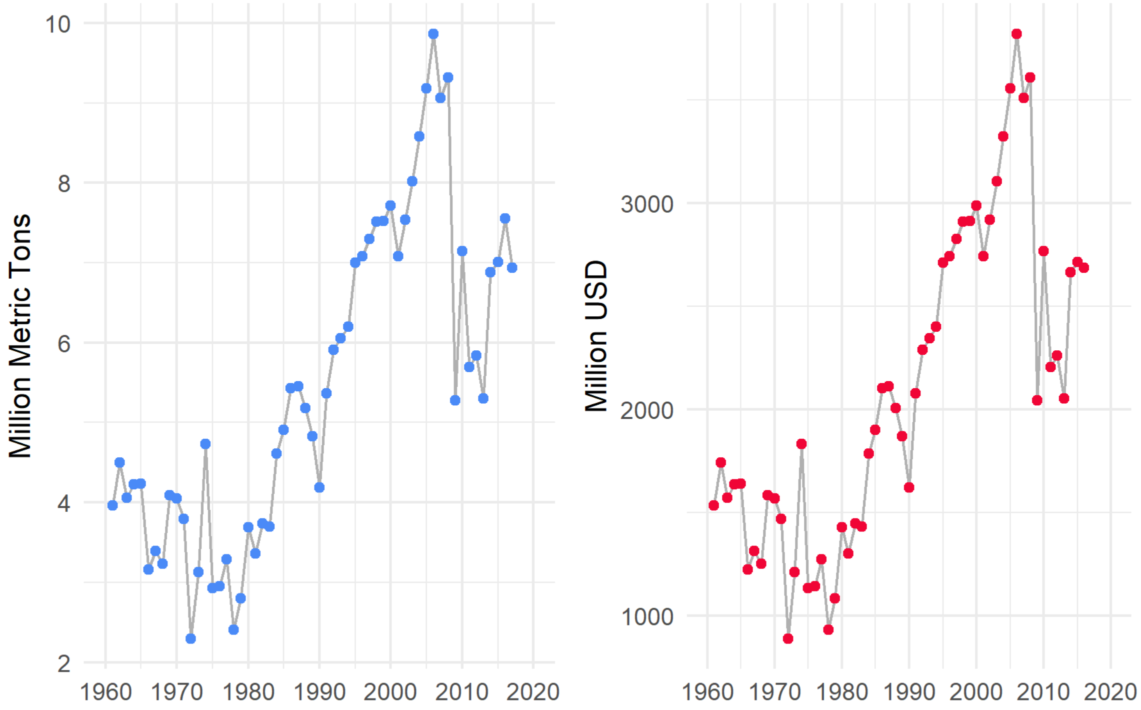
[lvi] https://www.k-state.edu/smil/

for local producers to access.[159] Because of this, many sorghum processors struggle to purchase sufficient quantities to maintain healthy capacity utilization for their equipment.[2]

Nigeria is the world's third largest sorghum producer and the crop accounts for about 5% of agricultural gross domestic product.[164] Nearly 100% of sorghum produced in Nigeria is consumed domestically, with roughly 70% going to human consumption and 30% to animal feed. In the long term, sorghum's perception as a "poor man's crop" may reduce the demand of customers who are able to buy other grains with increasing incomes **(Figure 45)**.[2]

Figure 45: Gross National Production (Left) and Gross Value (Right) of Sorghum in Nigeria[10]



Nigerian sorghum is not extensively traded beyond the country's borders, with formal imports and exports amounting to less than 1% of production.[10] The government imposes a five percent tariff on sorghum imports, though the net flow of sorghum is out of Nigeria, via 100,000 t of informal exports to Sahelian neighbors.[28]

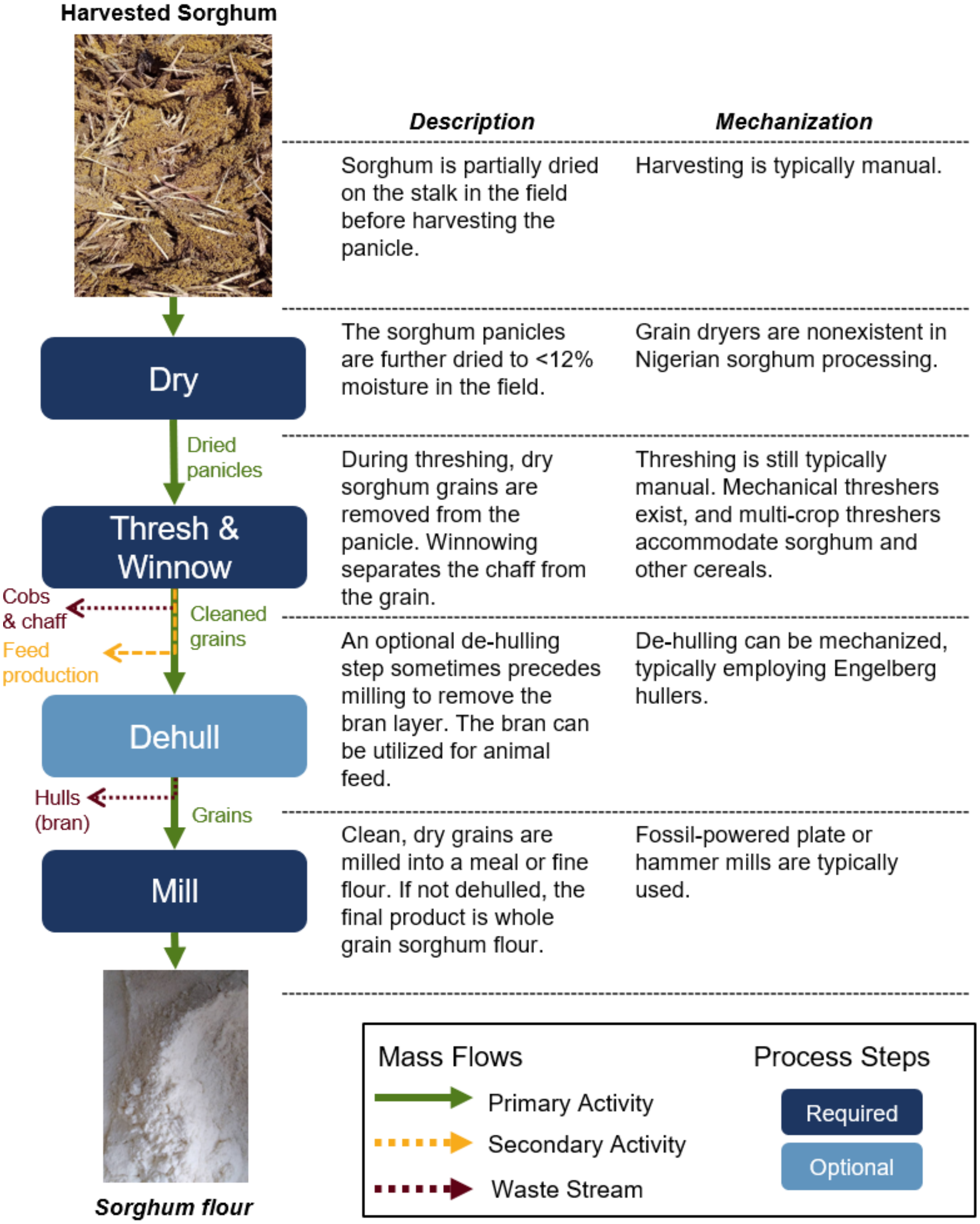
A.11.1.1 POST-HARVEST LOSSES

Sorghum post-harvest losses are not typically a concern if dried and stored properly (<12% moisture for threshed grain). [158] If not sufficiently dry before and during storage, molds and other microbes may accumulate. However, the dryness of the northern Nigerian climate—where sorghum is predominately grown—enables sun-drying to achieve consistent results. In Kaduna, no sorghum farmer we surveyed indicated trouble with sun-drying for more than one or two days per season. Insect damage is a bigger concern. One study of 160 sorghum farmers in Kwara state found 55% of respondents were using sacks for storage, with 70% utilizing an agro-chemical treatment to combat insect infestation.[154] Other natural insect repellents have been developed for use in concert with double or triple bagging,[165] but further investigation of these methods is beyond the scope of this study. As with all other grains, proper hermetic storage can significantly reduce damage by pests.[146] Once milled, sorghum flour has a shelf life of 3–6 months.

A.11.2 Value Chain Description

Sorghum is nearly always processed into a meal or flour before human consumption. We describe the process steps required to convert harvested sorghum panicles into sorghum flour in **Figure 46**.

Figure 46: Value Chain Steps from Harvested Sorghum Panicles to Milled Sorghum Flour

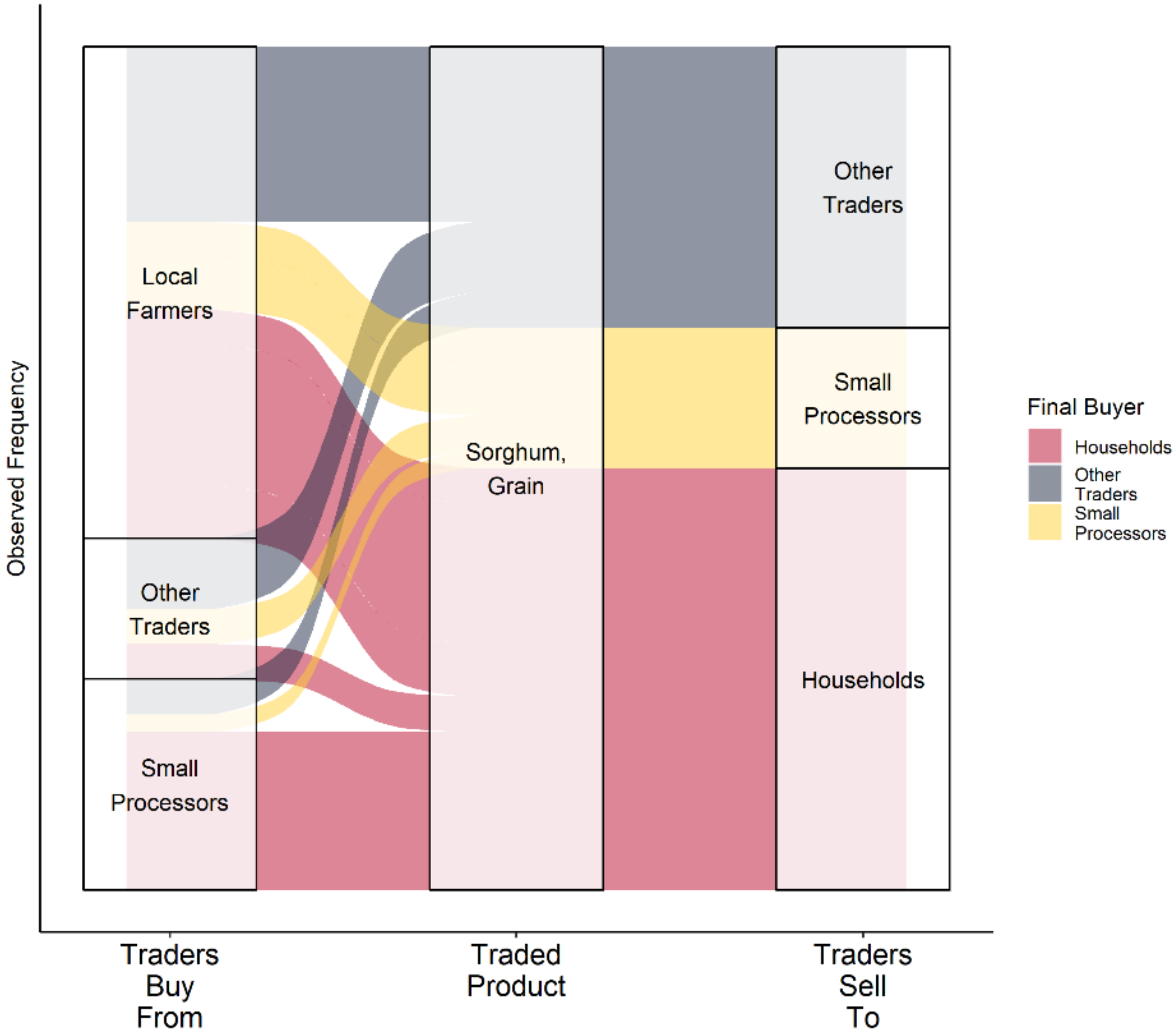


Description	***Mechanization***
Sorghum is partially dried on the stalk in the field before harvesting the panicle.	Harvesting is typically manual.
The sorghum panicles are further dried to <12% moisture in the field.	Grain dryers are nonexistent in Nigerian sorghum processing.
During threshing, dry sorghum grains are removed from the panicle. Winnowing separates the chaff from the grain.	Threshing is still typically manual. Mechanical threshers exist, and multi-crop threshers accommodate sorghum and other cereals.
An optional de-hulling step sometimes precedes milling to remove the bran layer. The bran can be utilized for animal feed.	De-hulling can be mechanized, typically employing Engelberg hullers.
Clean, dry grains are milled into a meal or fine flour. If not dehulled, the final product is whole grain sorghum flour.	Fossil-powered plate or hammer mills are typically used.

A.11.2.1 LOCAL SORGHUM TRADE

In surveyed communities, sorghum trade was observed between local farmers, processors, and households, with households as the most common final buyer **(Figure 47)**. Sorghum was one of the most localized crops analyzed in this study, fitting the patterns of self-consumption discussed above.

Figure 47: Frequency of Local Trade Flows for Sorghum in Surveyed Communities.



Flow size is proportional to the likelihood of the trade from source to final buyer.

A.11.3 Opportunities for Electrification in Sorghum Value Chain

Analyzing key considerations for sorghum flour production activities finds Tier 1 (dry milling), Tier 2 (threshing), and Tier 3 (mechanical grain drying) opportunities. These opportunities are similar to those for maize (**Appendix A.3.3**).

Sorghum Milling

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◕	From the evidence available, sorghum milling is a prevalent, mechanized process in mini-grid-suitable communities in Middle Belt and Northern states.
Offtake Market	◕	Local trade flows show strong demand for sorghum flours and meals.
Electric Equipment	●	Fossil-powered plate or hammer mills can be substituted by electric versions or retrofitted.
Scalability	◕	Most sorghum is milled before consumption and sorghum-producing communities will have milling capacity. However, if sorghum is not grown as a cash crop in mini-grid communities, volumes of sorghum milling may be low, requiring cross-crop equipment use.

Dried, threshed sorghum grains are typically ground into a flour or meal that is used to produce a variety of dishes. The taste and texture of sorghum meals is affected by the type of mill and how it is operated[166] but there is a shortage of literature on the specific practices of Nigerian sorghum millers. All three sorghum processors we surveyed utilized a mechanical mill but the true extent of mechanization in other states and communities is uncertain.

We classify sorghum milling as a Tier I activity by the same logic as for maize, cowpea, and soybean. However, the volume of sorghum produced in mini-grid-suitable communities may not be solely sufficient to sustain a milling operation. It is more likely that sorghum would be one of many cereals processed by a multi-crop mill (**Appendix A.1.2**).

A diesel flour mill for sorghum and maize processing in Joga 1, Kaduna. Owner Ismail Musa reports milling 400 kilograms of grain per day as a fee-for-service business.

Sorghum Threshing

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Capacity	◑	All sorghum farmers must thresh sorghum before selling the grains, but 100% of farmers surveyed utilized manual threshing.
Offtake Market	◕	Once threshed, sorghum grain is prevalently traded within mini-grid-suitable communities.
Electric Equipment	◕	Mechanical threshers exist and can be electrified if operated within the mini-grid service territory, but these devices were not in operation in the communities surveyed.
Scalability	◑	Sorghum is widely cultivated in semi-arid regions, but from the literature available, it is unclear how many mini-grid-suitable communities will produce sorghum quantities sufficient to justify mechanical threshing.

Traditionally, grains are threshed from the panicle by beating with heavy sticks or clubs. This method is time and labor-intensive, and often contaminates the grains with stones and soil. [2] One study claims that 80% of Nigerian sorghum was manually threshed circa 2006, though this number was not corroborated by the attributed source.[167] Mechanical threshers have been developed that can process sorghum in addition to other small grains such as maize, rice, or wheat. The considerations for sorghum panicle threshing are similar to maize cobs – unlike rice, both are detached from the stalk during harvest and thus could be efficiently transported to a centralized thresher.

Sorghum's tendency to be cultivated in smaller quantities for home consumption challenges the business case for mechanized threshing. Mechanical threshing is most beneficial when it decreases the labor costs associated with threshing a large quantity of grain. For small sorghum harvests, families are more likely to do the threshing themselves, and there is less time savings associated with transporting a small batch of dried panicles to a centralized thresher for processing versus a large batch.

We classify sorghum threshing as a Tier 2 opportunity for electrification, assuming it is co-processed with maize or other grains in the same threshing machine (**Appendix A.1.1**).

Sun-dried sorghum panicles ready for manual threshing in Damaski community, Kaduna state.

TIER 3

Sorghum Drying

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant

Local Capacity	◔	All sorghum grain is sun-dried, typically without incident. The value add of mechanical drying is unclear to farmers.
Offtake Market	◑	Sorghum is not yet an offtaker-driven market in most mini-grid-suitable communities, and thus is further behind other crops (e.g., maize, rice) in market development. It is unlikely that sorghum markets will value uniform, precise moisture content in the near term.
Electric Equipment	◔	Mechanical grain dryers commonly use fossil fuel as a heat source. All-electric options are in development but are unlikely to be cost-competitive with sun-drying at mini-grid tariffs.
Scalability	◔	Although sorghum cultivation is widespread, the demand for mechanical drying is probably low.

Sorghum must be dried before threshing, but this occurs naturally in the dry climates in which it is grown. In Kaduna, no sorghum farmer we surveyed indicated trouble with sun-drying for more than one or two days per season. Like for sorghum milling and threshing, the low volume of sorghum production per farm means that mechanical drying is only likely to be useful in combination with other cereals processing. We classify sorghum drying as a Tier 3 activity following our ratings for maize, rice, and cowpea drying as presented in **Appendices A.3.3**, **A.4.3**, and **A.9.3**, respectively.

Harvested sorghum panicles sun-drying in the fields prior to threshing in Takalafiya community, Kaduna state.

A.12 *Cotton*

- **Cotton is commonly grown by small-scale farmers as a cash crop in Nigeria,** but production is decreasing as farmers switch to other more profitable food crops.
- **Local farmers do not engage in cotton processing.** Almost all spinning, weaving, dyeing, and finishing is done at the industrial scale, but the textile industry in Nigeria is shrinking.
- At the farm level, major constraints to sector growth are in primary production (lack of access to farming inputs) and in cotton contamination during harvesting. **Neither of these limitations are directly addressable with electricity.**
- **No immediate-, medium-, or long-term electrification opportunities are identified.**

A.12.1 Crop Background and Market Characteristics

Cotton is farmed in three out of six distinct agroecological zones in Nigeria, and production is especially concentrated in the northwest part of the country where the weather is favorable for cotton.[168] Cotton was a major crop in 11% and 25% of communities we surveyed in Kaduna and Cross River, respectively. The cotton fiber grows in a boll around the seeds of the cotton plant. Cotton lint is stripped from the seeds then spun into yarn or thread and widely used to make a soft, breathable textile in garment industry.[9]

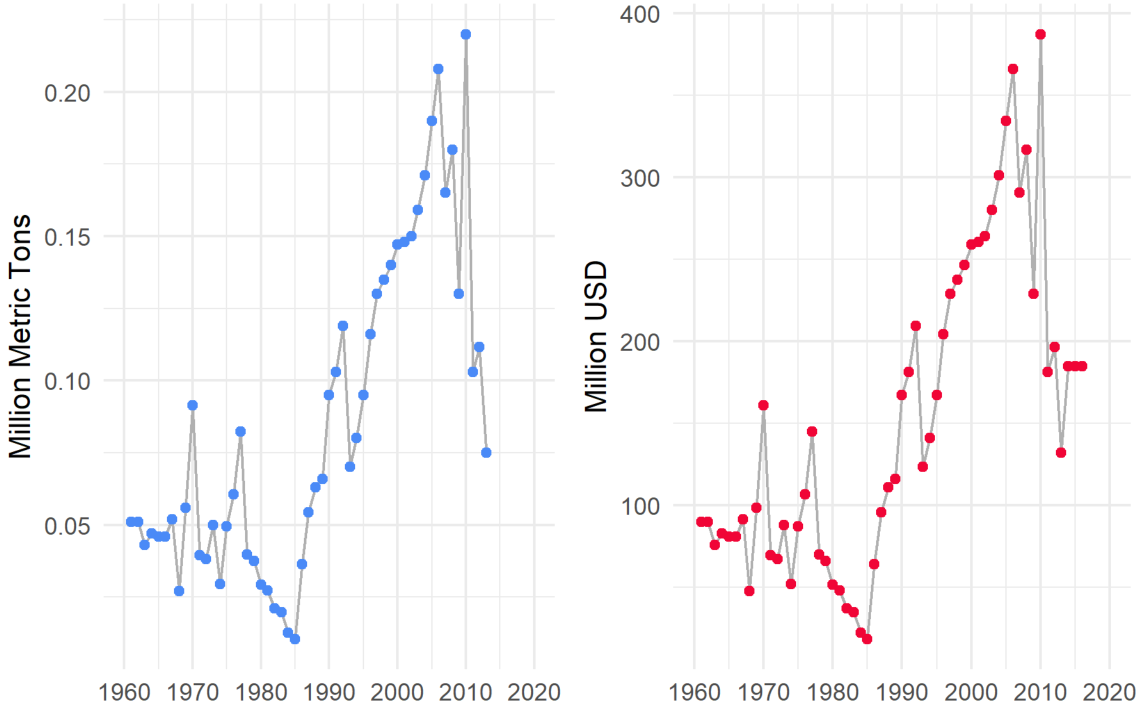
Cottonseeds are considered by-products in the process and are toxic to humans and most animals, but they can be industrially processed into edible oil and livestock feed. Cotton lint is the major product of Nigerian smallholder cotton farms.

Cotton is naturally a perennial, but it is usually grown as an annual to control pests. Most farmers plant cotton around June and expect harvest November and December. Nigerian cotton farms tend to be small, averaging two hectares in size.[9] In small-scale farms, cotton production is rarely mechanized. The bolls are usually handpicked three times, with the first picking beginning about 10 days after the opening of the first bolls and the second and third picking following in consecutive weeks.[168] Handpicked cotton is typically sold at a higher grade than machine harvested cotton.

Ogar Emmanuel Odama and his cotton in Gabu community in Cross River state. He farms 2 hectares of cotton from July to December and yields 250 kilograms of cotton lint per hectare.

Ginneries and textile mills in Nigeria absorb 100% of domestic cotton production.[9] In the 1970s Nigeria boasted Africa's largest textile industry with more than 180 textile mills supported by over 600,000 local farmers.[169] Unfortunately for Nigerian cotton producers, the industry has contracted since the 1990s due to high production costs, unreliable power supplies, and rising competition from globalization **(Figure 48)**.[170] Only 13 ginneries were reported to be active by the 2008–2009 season, and these were operating at low utilization rate (25–30%).[170] Low yields further contribute to the supply and demand gap. In 2018, yield in Nigeria was estimated at 0.85 t/ha compared to a world average of 2.2 t/ha.[10]

Figure 48: Gross National Production (Left) and Gross Value (Right) of Cotton Lint in Nigeria[10]



Production is very low relative to the other row crops in this study and has declined since 2010.

At the farm level, the cotton sector faces major constraints in access to farming inputs (quality seeds, fertilizers, pesticides, etc.), land preparation, harvesting, and post-harvest logistics. Farmers in our survey identified lack of financing as the top limitation for expanding their farming practice. Because of the high cost of labor in cotton production and relatively low profitability, many farmers are switching to other food crops.[9]

Surveyed farmers package harvested cotton in polypropylene bags, which contaminate the product and lead to uneven dyeing later in cotton processing.

The sector also suffers from lack of quality control—Nigerian lint is some of the most contaminated in the world due to the usage of polypropylene bags during harvesting.[170] The Federal Government has been working on an industry revival fund since 2004, establishing N100 billion in five-year, single-digit interest rate loans in 2009 and disbursing N60 billion of the fund by 2015.[171] Details on how exactly this fund has affected the sector as of March 2020 are difficult to obtain.

A.12.1.1 POST-HARVEST LOSSES

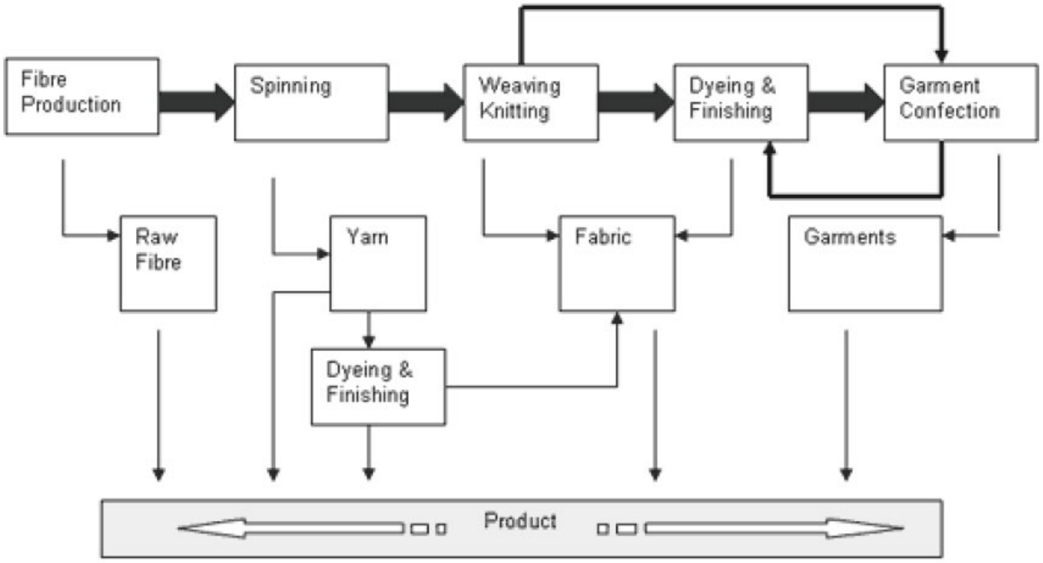
Farmers in Nigeria often use polypropylene bags when picking and delivering seed cotton to buyers and ginneries, resulting in contamination. Such contamination results in uneven dyeing of the fibers later in textile production, as the polypropylene absorbs the color at a different rate than the cotton.[170] In an effort to address this contamination, the Federal Ministry of Agriculture and Rural Development set up programs to distribute cotton harvest sacks and bags for free to farmers.

Bollworm infestation can cause 60% cotton yield losses.[169] In traditional farming practice, farmers rely heavily on pesticides, but planting genetically modified cotton provides built-in resistance. "Bt cotton" is engineered to resist insect infestation by producing natural insecticide in its tissue and eliminates the need to apply pesticide to crop regularly. In 2018, Bt cotton was the first genetically modified crop to be approved for commercialization in Nigeria, in hopes of raising yields ~seven-fold.[172] The GMO has achieved promising results in field tests and will be commercialized in the 2020 growing season.[173] Mahyco Grow — the Indian agricultural company who developed the GMO in collaboration with Ahmadu Bello University — is training farmers to properly produce and utilize the hybrid seeds.[173] The extent of Nigerian Bt cotton adoption is yet to be realized, but dramatic improvement in production could certainly affect the sector as a whole.

A.12.2 Value Chain Description

Figure 49 presents a generic value chain of cotton and textile industry. The process of converting cotton lint into yarn or textiles is complex, involving a series of highly complex machines that cannot be realistically run at the mini-grid community scale. **Textile industry equipment is expensive, requires significant expertise to operate, and needs substantial volumes of cotton to satisfy minimum capacity utilization thresholds. Thus, mini-grid-suitable communities are only involved in primary production of cotton lint or trading of the lint along the supply chain to industrial processors.**

Figure 49 Summary of Cotton and Textile Value Chain



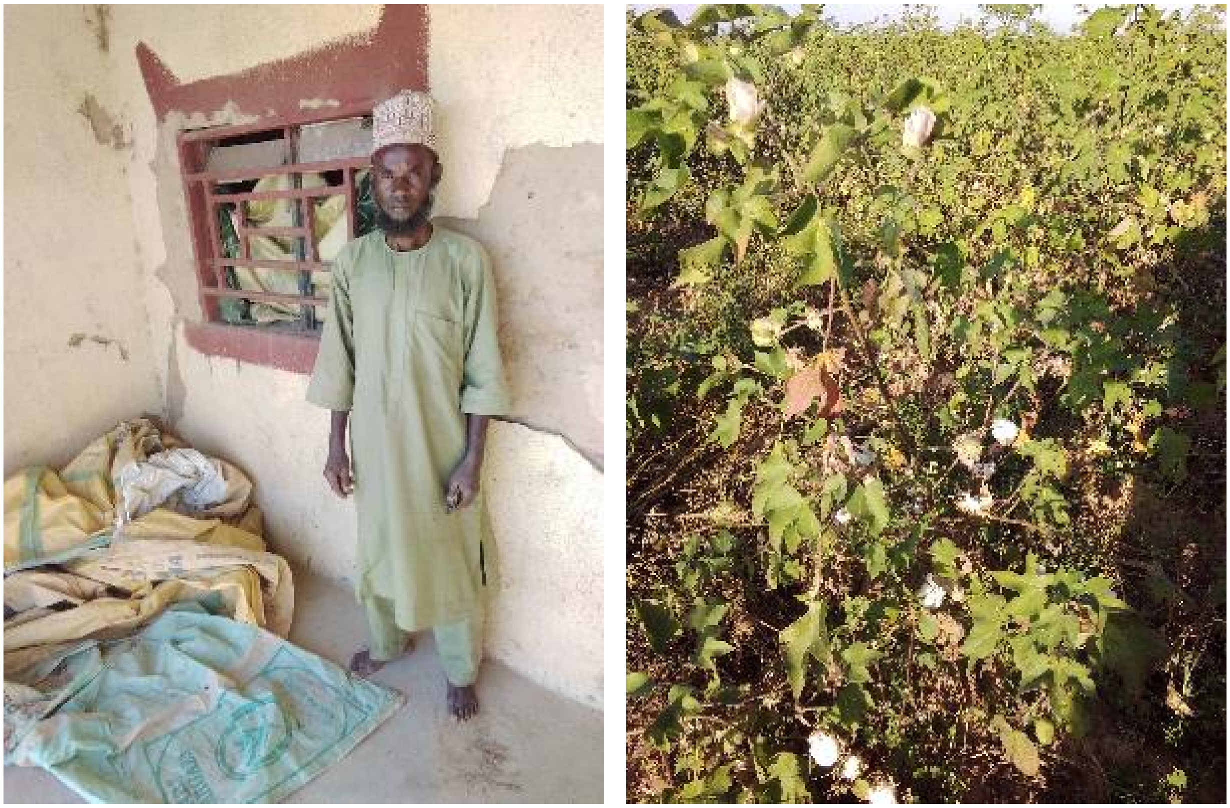
Excerpted from UNIDO, 2010.9

A.12.2.1 LOCAL TRADE

Upon harvest, cotton is spread out to sun-dry and then stored until a buyer arrives. Picked cotton is light yet bulky, making it hard to transport over a long distance cost-effectively. The low density of cotton combined with the inefficiencies in the supply chain transport infrastructure means that cotton farming communities must be within or nearby markets where cotton can be sold. In our survey, farmers usually sold cotton to markets or traders within their communities.

A.12.3 Opportunities for Electrification in Rural Cotton Value Chains

The complexity, expense, and scale of cotton processing precludes rural areas from most value-add opportunities. We have not identified any Tier 1, 2, or 3 opportunities for electrification through mini-grids for the rural cotton value chain in Nigeria.



Musa Idris (left) farms maize and cotton (right) in Dawan Malam community, Kaduna state. Mr. Idris irrigates his fields with petrol pumps and reports yields around 1 t/ha, but he loses about 25% of his crop each year to pests.

A.13 *Shea Nut*

- **Nearly all Nigerian shea nuts come from wild-grown trees,** with no sign of significant production increases in the near term.
- **Shea nuts and products are largely consumed locally and do not reach broader domestic and international markets.**
- **Leading experts prioritize market development interventions to enable local producers to sell high-quality dry kernels for elevated prices to industrial extractors.** Most do not advocate for increased local mechanized processing.
- There are many steps involved in shea nut processing. **While mechanization is possible for some of the steps, significant efforts are required to first establish an extended value chain, conduct local capacity building, and ensure quality control.**
- **Using semi-mechanized processing could improve butter extraction yield and efficiency,** but the underdeveloped value chain only processes small volumes today and collecting sufficient volume for mechanized processing is likely to be challenging.

A.13.1 Crop Background and Market Characteristics

Shea tree fruit.

Shea nuts are the fruit seeds of shea trees, which grow in 13 Nigerian states.[174] The shea tree is indigenous to a large swath of Africa, and grows to a height of 7–15 meters during its >200-year life span. [175] Newly-planted trees do not bear fruit[lvii] for 10–15 years, reaching full production during their second, third, or even fourth decade of life. The National Institute for Oil Palm Research in Nigeria has developed domesticated shea nut seedlings with a 5–7-year gestation time.

A mature tree can produce 3–5 kg of dry nuts per year, but may not be productive each year.[176] Agroforestry parkland systems, in which shea is the dominant species of biomass left standing, are the most intensive shea cultivation systems.[177] But more extensive farming of other crops has displaced shea from the fallow lands where they have historically regenerated, and thus shea tree populations in many communities have been in decline for decades. [178] Decline of native pollinators — mainly bees, driven by clearing of natural habitat — is another potential driver of yield decline. [179]

During the rainy season, the mature, edible fruits fall from the tree and are typically collected by women and children. For millennia, the oleaginous nuts have been prized for their versatile fats, which can be used for cooking, skin care, soap-making, fire-lighting, and waterproofing roofs .[180]

Shea nuts are important sources of income for the women who harvest and process them, but these producers are usually price takers during the busy harvest season and lack the market access and means to sell higher-quality nuts for higher prices. Even quality kernels that ultimately fetch high prices in foreign markets later in the value chain are bought from rural producers at the low-quality kernel price.[181] Shea nuts are sold throughout the year but the majority are sold within the first three months after harvest.[174] Farmers tend to sell shea nuts to local traders at the nearest market or process nuts into small batches of butter. Most shea nuts are consumed locally without even reaching domestic markets. Since local

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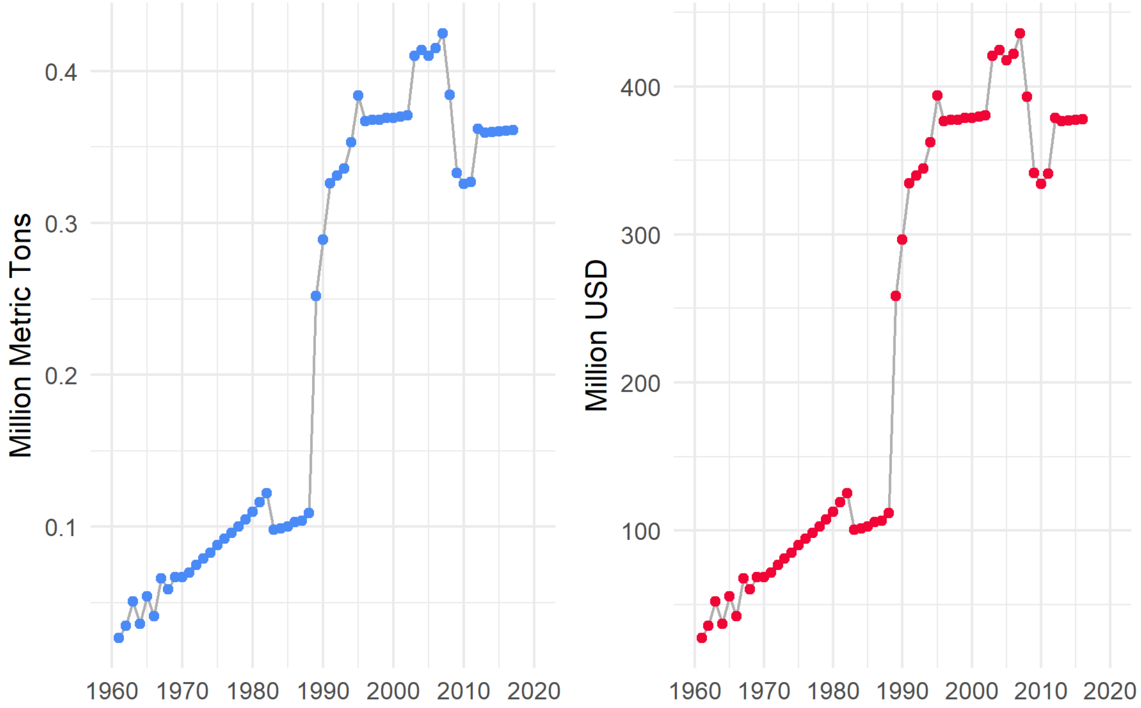
[lvii] Photo by Marco Schmidt, West African Plants Photo Guide

producers rely on collecting fruits from naturally occurring trees, they have little immediate means to intensify production without planting new trees and waiting about a decade for the new tree's first fruits.

Globally, shea is an important natural source of stearic acid prized by the chocolate and cosmetics industries.[181] Nigeria is a major producer of shea nuts **(Figure 50)**, accounting for about 50% of global production in 2016, but only a fraction is formally exported. In 2016 only 638 tons, or 0.2% of estimated total production, were exported.[10] Dry kernels are exported whole, because they are easy to store and because importers prefer to maintain control over the quality of processing the kernels into shea butter.[180] Manually-extracted butter from small-scale operations does not meet export standards today.[182] In the 80s and 90s, a few cosmetics companies attempted to source shea butter directly from local women, however the scale of these programs were ultimately several orders of magnitude lower than the volume needed for the companies' industrial processing facilities.[181]

Figure 50: Gross National Production (Left) and Gross Value (Right) of Shea Nut in Nigeria[10]



A.13.1.1 POST-HARVEST LOSSES

Once cured to dry kernels, shea nuts are stable for more than a year if stored in a dry, aerated environment.[180] Like maize and other cereal grains, shea nuts are vulnerable to fungal contamination (e.g., aflatoxins) when they are not fully dried. Since the main harvest is during the rainy season and sun-drying is the exclusive practice, fungal damage seems to be relatively common, though reliable estimates on contamination rates are difficult to obtain.

Inconsistent post-harvest handling practices may also affect the quality of the nut fats before trading of the dry kernel. The length of time between fruit maturation, harvest, drying, and whether there is a heating/roasting stage affect free fatty acid (FFA) levels in the extract.[183] Further quality degradation can occur via a variety of process missteps, raising peroxide levels and accumulating polycyclic aromatic hydrocarbons and unsaponifiables.[180] All can affect the value of kernels and shea butter processed.

Amina Haruna (left) processes shea nuts (right) into shea butter, which she sells in her community of Bature, Kaduna state. Mrs. Haruna uses wood to heat her parboiling pot, sun-dries the kernels, and processes to butter by hand.

A.13.2 Value Chain Description

In Nigeria, shea nut is primarily processed by traditional methods involving little to no mechanization. The procedure is labor-intensive and mostly done by women in rural areas. **Figure 51** presents how shea fruits are processed into shea butter in rural communities.

There are two distinct stages in shea processing: 1) production of dry kernels, 2) processing of the kernels into shea butter. All shea fruits proceed through phase 1 to yield dry kernels. Once extracted from the fruit, boiled, de-husked, and dried, kernels are shelf stable and can be sold up the value chain to industrial processors. In our limited observation of shea trade, these dried kernels were the exclusive good moved by traders.

In a second phase of value-add processing, some women extract small batches of shea butter from their dried kernels. The process requires a large quantity of water and heating fuel and is time consuming. Two recent studies estimated that traditional methods use between 0.5–2.5 kilograms of wood fuel and 3.5–6 liters of water for every one kilogram of raw shea nuts processed into butter.[180,184] One batch of shea butter requires an estimated 20–30 hours of labor. [185] Semi-mechanized operations may use attrition mills, crushers, or kneaders to improve worker efficiency, but a large processing volume is required to justify the initial cost. After crushing, roasting, grinding, emulsifying, and fat-skimming steps, the shea butter is cooled and solidified before sale in small plastic containers or bowls.

In industrial processing, butter extraction is followed by an additional refining stage that "clean" the butter further by removing gums, neutralizing free fatty acids, and removing resulting traces of soap, bleaching, and fractionation into stearin (creamy fat, used in foods) and olein (runny oil, used in cosmetics).[180]

Without a refining stage, local shea butters cannot be integrated directly into commercial cosmetics or foods. But the refining processes require chemists, engineers, quality-control, and industrial equipment that is far beyond the capacity of mini-grid-suitable communities.

A.13.3 Opportunities for Electrification in Rural Shea Nut Value Chains

As discussed above, shea nuts are sold either as dried kernels or a traditional raw shea butter. Kernel production entails parboiling and drying nuts using traditional practices, and we refer readers to our analysis of these operations in other value chains. **Box A.4 in Section A.4.3** analyzes the viability of electric parboiling of rice, finding it very unlikely to compete with wood parboiling. Efficient, improved parboiling vessels that reduce wood fuel consumption are the most viable near-term solution for this activity. **Appendix A.6.3** discusses the viability of cocoa drying, which is analogous to shea nut drying practices. A simple passive solar dryer that amplifies solar heating and provides cover from rain is more likely to cost-effectively solve drying problems.

We consider shea butter production separately from kernel production. Similar to cashew kernel production, shea butter operations from dried kernel to raw butter necessarily happen in one location — process intermediates are not traded between processors. Given the small-scale of production of farmers and local processors, and low potential to quickly expand shea production in a given area, we classify shea butter production as a Tier 3 opportunity for electrification with mini-grids.

Hafsat Abdullahi makes N1500 per week by processing small batches of local shea nuts into shea butter using traditional preparation methods.

Figure 51: Summary of Shea Butter Processing Steps for Small-Scale Producers

Shea Fruits	***Description***	***Mechanization***
De-pulp, Boil & Dry	Remove the pulp manually then wash the nuts. The nuts are boiled in water in large metal pot for about two hours, then laid on ground or mat to sun-dry.	Wood-fueled parboiling fires and sun-drying are the predominant methods. Few use ovens to dry their nuts.
De-husk & Dry	Crack the shell to remove the kernels, then sun-dry the kernels again. Clean kernels can be packed in bags and stored until processing and sale.	De-husking is done manually with mortar and pestle. Sun drying is predominant practice.
Crush	Pound the kernels to crush into grits.	This labor-intensive process is typically manual. Mechanized crushers exist.
Roast	Roast the kernel grits to facilitate oil extraction	Performed in a large iron pots over an open fire. Over-roasting can degrade quality. Ovens could also be used.
Mill/Grind	Roasted kernel grits are ground into a paste	This is commonly manual but can also be done with attrition mills.
Emulsify	Knead the paste in water to capture the fat into emulsion, then boil the mixture to separate fat	Manually performed, but a common kitchen mixer can be utilized as well.
Skim Fat & Cool	Skim off fat from the mixture, then let it cool into smooth cream. The crude butter is packed to plastic container or calabash.	

Photo: flickr @daveynin

TIER 3

Shea Butter Production

Support Required: ● Deployment-Ready – ◕ Minimal – ◑ Moderate – ◔ Significant		
Local Know-How	◑	Small batches of shea butter are processed, typically by women in shea-producing communities. Their operations rarely utilize mechanization.
Offtake Market	◔	Locally made shea butter is not refined and therefore cannot directly connect to industrial markets.
Electric Equipment	◑	Semi-mechanized operations may use attrition mills, crushers, or kneaders to improve worker efficiency, but a large processing volume is required to justify the initial cost.
Scalability	◔	Shea nut production is low in volume per unit area, relying on collection of naturally growing nuts. Unless a mini-grid-suitable community is near a confluence of multiple shea-producing communities, it is very unlikely that the capacity utilization requirements for semi-mechanized shea butter production can be met.

Mechanization is possible in several steps of shea butter production, particularly in crushing, attrition milling, and kneading. However, the volume of shea nuts processed by a given producer is very low relative to the cereal grains considered in this study. One survey of 150 shea processors in Niger state estimated a typical annual butter production of 800 kilograms per business.[186] Another study in northern Ghana found that an average processor could convert 85–100 kilograms of dry shea kernels into 30–40 kilograms of shea butter over a three day period in peak season.[181] **At these typical micro-processor throughputs, the size of shea butter appliances is roughly kitchen-scale.** In urban Ghana, semi-mechanized processors required 0.3–0.6 kWh electrical energy per kilogram of shea butter (9–24 kWh per batch), reducing labor time by roughly 40% compared to manual processors.

Medium-scale facilities could theoretically process the collective output of thousands of growers at a profit but would likely struggle to maintain reasonable capacity utilization. A 2018 study estimated that a $2,650 investment in a sheller, crusher, steam roaster, miller, and mixer could enable profitable production of 270 kilograms of shea butter per day.[187] **However, sustaining this plant's 600 kg/day crushing capacity for one year would require the annual production of roughly 30,000 shea trees, or the seasonal collection of roughly 3,000 shea nut producers** (assuming 260 days of processing, 5 kg/tree/year, and a typical collection rate of 50 kg/season/producer, based on field survey data). Even fulfilling a tenth of this throughput would be challenging given the low yields of shea parklands. Some mini-grid-suitable communities may be situated near the critical volume of shea nut production required to sustain semi-mechanized shea butter processing, but the business case will depend upon the ability of the operator to collect naturally-occurring shea over a large geographical area. Further, because shea trees are not commercially cultivated, the operator would not be able to reliably intensify production of nearby trees without establishing a parkland of their own and waiting the ~10 years before first fruits are born.

Thus, **'kitchen-sized' crushers, grinders, and mixers that operate at the micro-processor scale are more promising tools for electrifying rural shea butter operations**. However, these smaller devices are powered by ~150-Watt motors and are more akin to home kitchen appliances than the scale of productive use equipment considered across the other value chains in this study.

APPENDIX B VENDOR DATABASE

While RMI did not conduct an extensive survey of local and international equipment availability as part of this study, this database provides a preliminary list of vendors that fabricate and import various agricultural equipment for Tier 1 and Tier 2 activities. The table below provides a database of manufacturers. Many of these manufacturers are members of AMEFAN (see **Appendix F**) and international manufacturers that sell their equipment in Nigeria. Additional research will be required to confirm equipment availability in specific areas of Nigeria, and to test equipment in rural settings.

Table 11: Sample of Agricultural Manufacturer and Equipment Sold in Nigeria

Name	Crop	Equipment Available	Manufacturer
Damax Nig	Cassava	Dryers, Graters, Peelers	Local - AMEFAN
Blessed Silver Bros Limited	Cassava	Cabinet Dryer, Graters, Tray Fryer	Local - AMEFAN
Confidence Technical Work Enterprise	Cassava	Cabinet Dryer, Graters, Tray Fryer	Local - AMEFAN
E. K. Fabricating Engineering	Cassava	Hydraulic Presses, Grater, Fryers	Local - AMEFAN
Muhat Nigeria	Cassava	Cabinet Dryer, Graters, Tray Fryer	Local - AMEFAN
Basicon Engineering Company	Cassava	Dryer, Hydraulic Press	Local - AMEFAN
Dan Oguike & Sons Enterprises	Cassava	Hydraulic Press, Dryer	Local - AMEFAN
Divine Engineering Works	Cassava	Graters, Dryers	Local - AMEFAN
Emeka & Sons Construction Company	Oil Palm	Graters, Dryers	Local - AMEFAN
Hanigha Nigeria	Grains/Cereals	Threshers.	Local - AMEFAN
Kenny Construction Company	Soybeans	Destoners, Cookers, Crushers	Local - AMEFAN
Muharib Machine	Grains/Cereals	Corn Threshers, Plate Mills, Hammer Mills, Feed Mixers	Local - AMEFAN
Alayan Metals Fabrication Nig	Cassava	Hammer Mill (Wet), Hydraulic Press, Hammer Mill + Cyclone (Dry)	Local - AMEFAN
Niji Lukas Nig	Cassava	Hydraulic Dewatering Presses, Mechanical Rotary Fryer, Flash Dryers, Hammer Mills	Local - AMEFAN
Alanco & Son Steel Fabricator	Grains /Rice	Hammer Mill, Vertical Mixers, Pre-cleaners	Local - AMEFAN
Deban Faith Ventures	Cassava	Grater, Press, Flash Dryer, Hammer Mill	Local - AMEFAN

Name	Crop	Equipment Available	Manufacturer
Alaral Tech Engineering Design & Fabrication	Rice	Rice Threshers, Pre-cleaners, Parboilers, Dryers, Huller/Polisher	Local - AMEFAN
Amadis Technical Company	Cassava	Grater, Press, Sifter, Fryer	Local - AMEFAN
Lawod Metal Nig	Cassava	Grater, Press, Fryer, Sifter	Local - AMEFAN
Sominie Nigeria	Rice	Miller	Local - AMEFAN
Adebash Manufacturing Company	Cassava	Grater, Presses, Fryer, Sifter	Local - AMEFAN
Fatoroy Steel Industry Limited	Cassava	Mechanical Peeler, Grater, Press, Fryers	Local - AMEFAN
Process Concepts & Technologies	Rice	Pre-cleaner, Thresher, Rapid Steam Parboiler, Flat Bed Dryer	Local - AMEFAN
Tropical Development Engineering Limited	Cassava	Grater, Press, Fryer, Sifter	Local - AMEFAN
Besuga Global Investment	Cereals/Grains	Dehuskers, Hammer Mill, Destoner, Mixers	Local - AMEFAN
Gensaes Enterprises	Cereals/Grains	Grinders, Dehullers, Wheelbarrows	Local - AMEFAN
Teekay Engineering Services Ltd	Cereals/Grains	Mechanical Dryers.	Local - AMEFAN
Apexskill Works	Groundnuts/Rice	Thresher, Toaster, Oil Expeller, Filter Press	Local - AMEFAN
Bifem Technologies Nigeria	Cassava	Grater, Fryer, Peelers	Local - AMEFAN
PAF Metal Fabrication and Youth Development	Cassava	Grater, fryer	Local - AMEFAN
S.Adiss Engineering Works	Grains	Pre-cleaners, Hammer Mills, Vertical Mixers, Screw Conveyors	Local - AMEFAN
Sunday Omowaye	Grains	Rice processing Machine	Local - AMEFAN
Kola Adekunku	Cassava	*Gari* Processing machines	Local - AMEFAN
Olaleye Eliseri	Cassava	*Gari* Processing machines	Local - AMEFAN
Segun Towoju	Cassava	*Gari* Processing machines	Local - AMEFAN
Ibraham Onsachi	Cassava	*Gari* Processing machines	Local - AMEFAN
DEE Technical	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
Bomik Adeyeera Engineering	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
Pentawork Technical Work	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
N.C. Gilbert Ind Dev Co	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
ESE Engineering Service	Cassava	Graters, Dryers, Peelers	Local - AMEFAN

Name	Crop	Equipment Available	Manufacturer
Eamak Technical Services	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
Magi Rches Limited	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
Talitha Fabrication Company	Cassava	Graters, Dryers, Peelers	Local - AMEFAN
Sakilan Engineering Company	Cassava	Graters, Peelers, Dryers	Local - AMEFAN
Peak Products	Cassava	Flash dryer, Peelers, Graters	Local - AMEFAN
Oladimeji Success	Cassava	*Gari* Processing machines	Local - AMEFAN
Doing	Cassava	Peeler	Foreign
Goodway	Cassava	Peeler, Miller	Foreign
Henan Doing	Cassava	Grater, Miller	Foreign
Zheng Zhou Sida	Cassava	Grater	Foreign
Arcadem	Cassava	Grater	Foreign
Starron	Cassava	Grater	Foreign
Nui-Lukas	Cassava	Grater	Foreign
Weilai Machinery	Rice	Compact Rice mill	Foreign
Zheng Zou Sida	Rice	Compact Rice mill	Foreign
Nova Technologies	Cassava	Grater	Local
Bennie Agro	Cassava, Rice	Multipurpose Thresher, Grater, Miller, Multipurpose miller	Local
MCAN	Cassava, Rice, Maize	Grater, combined grater/chipping, multi-purpose thresher, miller, *Gari* fryer, dryer	Local
UNIC & Sons	Cassava, Grains	Cassava Grater, Rice Mill, Multipurpose Miller, Rice Mill, Multipurpose thresher, Maize Thresher	Local
Chinige Technology Services LTD	Grains	Rice Mill, Multipurpose thresher, Maize thresher	Local

APPENDIX C ECONOMIC MODELING

This appendix presents an overview of the methodology used to assess the economic viability of the Tier 1 activities and the impact on mini-grid economics. Detailed cash flow analyses and sensitivity analyses results are also included in **Appendices C.2 to C.4.**

C.1 *Methodology for Assessing Economic Viability*

Before describing the cash flow model and assumptions, we first explain how we choose the activities to model and then describe the approach used.

C.1.1 Selecting processing activities and equipment

As noted above, we select processing activities that are identified as Tier 1 (see **Section 3.1**) for analysis. Milled rice and grain flour, the immediate products after rice and grain flour milling, are common forms of product that are directly traded. As such, we can model the value add from the milling process alone. Grated cassava, however, will go through additional processing steps before the products are sold in *gari* form. It's difficult to properly measure the value of grated cassava alone and no current processors only provide grating service, hence in our analysis, we examine the whole process turning cassava tubers into *gari*, then try to isolate the contribution from the grater assuming other machinery and costs in *gari* production remain the same.

Because cassava grating, rice and grain flour milling are mechanized activities existing in surveyed areas, we model introducing electric equipment alternatives both as a new investment and as a replacement of existing fossil fuel-powered equipment. From survey respondents, two modalities are common—processors purchase raw materials then sell the processed products (BnS modality) or they charge a fee for processing service provided per kilogram (FFS modality), are common for cassava processing and rice milling. But for grain flour milling business, fee-for-service is predominant and all survey respondents process maize (only a few in addition process sorghum or other grains). Maize flour milling with fee-for-service modality is thus analyzed to assess the economics of maize and other grains.

Based on consultations with equipment providers, we select specifications (capacity in kW) of equipment commonly found in Nigeria and that can meet current processing demand in a small-scale business.[lviii]

C.1.2 Analytical tools and assumptions

The cash flow model calculates the net present value ('NPV') of equipment investment including the following cost categories: capital cost of equipment, financing cost, operating and maintenance cost, facilitator fee and potential revenues from the processing business.[lix] When comparing with existing fossil fueled-powered equipment, "net" cost and "net" revenues are used for the cash flow calculation.

We base most input data on survey results, such as daily processing volume, hours of processing business, sale price, fuel cost, maintenance cost. With exception for processing volume, we use the median value of all survey responses to capture the central tendency of survey results, as average values can be biased by outliers. We adopt the 25th percentile for volume to be more conservative (see discussion in subsection of each crop—**Appendix C.2, C.3** and **C.4**). When possible we cross reference numbers from the literature review to sense-check the assumptions used. For other input fields not included in the survey or for which we did not receive enough responses, we base our assumptions from the literature review and RMI's previous research and analysis**. Table 12** shows the overarching assumptions used across each

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[lviii] Maize flour milling for example, survey respondent reported a daily processing volume of about 300 kg. A 2 ton/hour mill is available in the market in Nigeria, but unnecessary for such a small business.

[lix] The calculation in the model is in US dollar, and the exchange rate used is 1 USD ≈ 363 Naira.

activity. Crop specific input sources and references are noted in subsections explaining cash flow analysis results of each Tier 1 crop (see **Table 15, Table 17** and **Table 19**).[lx]

Table 12: Overarching assumptions used in economic viability analysis.

	Assumption	Explanation
Electricity cost	Mini-grid electricity tariff is \$0.60/kWh.	This reflects current best practice based on RMI experience[lxi]; sensitivity analysis of tariff is also conducted.
Electricity time-of-use (TOU) rate	We assume 20% TOU discount offered during 8am–4pm.	TOU discount is available during time that the sun is shining. Sensitivity analysis of TOU discount is conducted.
Equipment usage	Usage profile of new electric equipment—hours of operation, equipment capacity level will remain the same as business as usual (BAU) (as reported in survey).	Without other incentives, processors are most likely to maintain current schedule of business.
Production volume	With electric equipment, daily production volume will remain the same as BAU (as reported in survey). Percentage of actual running time in an hour might be adjusted to match production volume.	Without other interventions, market demand will stay the same. Even if the new equipment can process higher volume, this assumption reflects a more conservative estimate. For example, based on the survey processors on average process around 2,500kg of cassava daily, now with new equipment, we assume they will process 2,500kg daily as well. Sensitivity analysis of production volume is later conducted.
Sale price and FFS charge	Service charge and sale price of product processed by electric equipment will be the same as BAU (as reported in survey).	Without other interventions, market conditions will stay the same. Even if newer equipment might produce higher-quality products, we assume sale price and service charge will remain the same as BAU. Sensitivity analysis of sales price and FFS charges are also conducted.
Self-consumption	Assume all products are for sale.	Although self-consumption is common based on the survey, the value of the products exists whether processors decide to sell or consume. To reflect the total value of processed goods, we assume 0% self-consumption.

[lx] Assumptions and data source are also noted in corresponding cell in the Excel model.

[lxi] Agenbroad, J., Carlin, K., Ernst, K. & Doig, S. Mini-grids in the Money: Six Ways to Reduce Mini-grid Cost by 60% for Rural Electrification. (2018).

	Assumption	Explanation
Interest rate and loan tenor	We assume a 5-year loan with interest rate of 30% and this is real interest rate. When calculating NPV, the weighted average cost of capital (WACC) is used as discount rate.	Based on stakeholder interviews, we understand that 30% represents the market cost of capital for the agricultural sector. We choose a long-term loan that is better suited for agricultural sector investments where margins can be low and returns volatile. The payback periods of the investments range from 1 to 4 years and align with this assumption. Sensitivity analysis on debt interest rate is also conducted.
Financing structure	We assume 100% debt financing. WACC in this case equals debt interest rate.	In rural Nigeria, ability to pay is low and borrowers lack sufficient savings to afford an equity contribution. Sensitivity analysis of grant percentage is conducted.
Facilitator fee	We assume 25% facilitator fee on the loan amount.	Facilitators will vet and select processors, carry out capacity building and outreach activities to train and raise awareness. The amount is based on the literature review and expert interviews, see **Appendix E.3.3** for additional detail
Maintenance savings	We assume 50% maintenance savings using electric equipment compared to fossil fuel powered equipment.	Studies have shown that maintenance cost of electric motor is usually lower than diesel motor and expert interviews with AMEFAN confirm this.[lxii]

C.1.3 Sensitivity analysis approach

We conduct sensitivity analyses to evaluate which variables may drive investment economics and have an outsized impact on NPV and payback. To isolate impact of changes, the sensitivity analyses test the following variables (see **Table 13**) in isolation while keeping other model inputs fixed.

Table 13: Summary of sensitivity variables analyzed.

Sensitivity variable	Range of change	Description
Production volume (kg/year)	-50%, +50%	This shows how the economics of the equipment investment are affected if production drops due to poor harvest, weather, or other crop related issues, or if production grows due to business expansion
Capital expenditure of equipment (capex, $)	-50%, +100%	Shows how changes in cost of the equipment impacts the economics of the investment
Electricity price ($/kWh)	-50%, +100%	Shows how mini-grid tariff will impact the economics of the investment
Electricity Time-of-Use (TOU) discount	-100%, +100%	
Sale price (for BnS modality, $/kg)	-50%, +50%	Shows the sale price/charge needed to make the business profitable

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[lxii] https://www.pumpsandsystems.com/powering-pump-diesel-versus-electric-motors

Sensitivity variable	Range of change	Description
FFS charge (for FFS modality, $/kg):	-50%, +50%	
Facilitator fee (as % of loan)	-100%, +50%	Shows how much processors can afford to pay for a facilitator's services
Grant ratio (%)	0, +400%	Shows the impact of grant/subsidy
Debt interest rate	-50%, +100%	Shows the impact of cost of capital on returns and the cost of debt that processors can afford
Loan tenor (years)	-4 years, +5 years	
Lifespan (years)	-5 years, +5 years	Shows how equipment lifespan impacts the economics of the investment

C.1.4 Streamlined approach for the mini-grid economic analysis

To enable us to carry out this additional mini-grid economic analysis in a streamlined way and meet project deadlines we use RMI's existing tools, analysis, and load survey data from across Nigeria. To do so, we reference the number of households and the number of agriculture processors per community for each crop from our survey results in Kaduna and Cross River states. This is cross-referenced with existing RMI mini-grid analysis and load survey results from across Nigeria to estimate hourly power consumption across residential and commercial loads in the community. To conduct the economic viability analysis of electrifying Tier 1 activities, we then use agricultural processor survey responses to develop 24-hour load profiles for electric cassava graters, rice mills, and grain flour mills, and subsequently estimate annual (8,760-hour) load profiles considering processing seasonality and days of operation. These load profiles are then inputted in HOMER to size the mini-grid system.

In HOMER, we set the discount rate at 10%, inflation rate at 2%, project lifetime at 20 years. We assume maximum annual capacity shortage is 0%, and 10% load plus 80% solar output are required as the operating reserve requirement. All are default values in HOMER.

Based on the mini-grid design and operations, RMI's mini-grid financial model is used to calculate the tariff required for developers to achieve a 15% IRR over a 20-year project lifetime, with potential additional capital investment every four years to accommodate growing demand. We assume a 25% grant for the initial mini-grid capital expenditure, and model diesel cost at $0.66/L, cross referencing market data, survey data, and previous site visit data. Cost inputs, including mini-grid system components, project development, O&M and etc., are largely based on RMI 2018 research data.[lxiii] For simplicity, we assume a single tariff is applied to all customer groups and that existing customer consumption behavior will not change with implementation of mini-grid. For example, cassava processors will maintain their current operating schedule, not changing it to match solar generation.

The following subsections discuss analysis results in detail for each processing activity modeled.

[lxiii] Agenbroad, J., Carlin, K., Ernst, K. & Doig, S. Mini-grids in the Money: Six Ways to Reduce Mini-grid Cost by 60% for Rural Electrification. (2018). See *Appendix: Analysis Methodology and Assumptions* for detailed cost breakdown.

C.2 *Economic Viability Analysis: Cassava Gari Production*

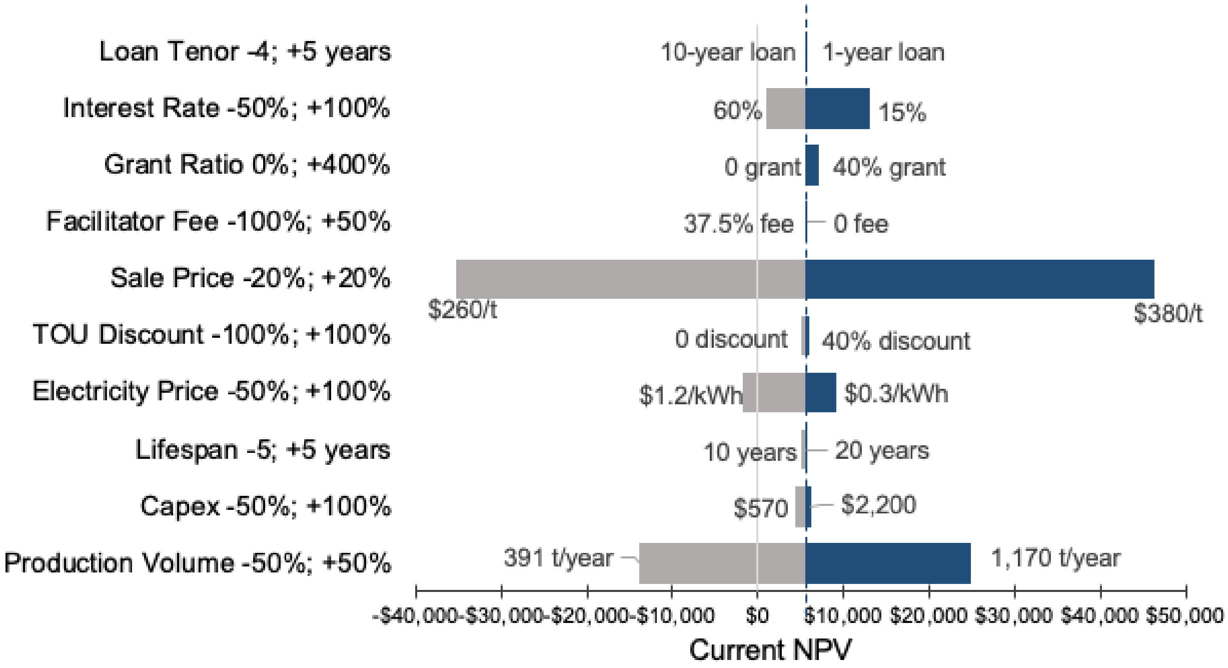
The most predominant processing of cassava in rural Nigerian communities is for *gari*, and grating is a key step that requires significant mechanical energy. Considering the process of *gari* production, we find that electric grating is a compelling investment. At the processing volumes indicated in our survey, both buy and sell (where processors buy cassava tubes then sell *gari*) and fee-for-service (where the processor charges community members a fee for processing their cassava) sales modalities are economically viable. Investment NPVs range from $2,900 to $5,500 and allow processors to recover their investment in two to three years (see **Table 14**).

Table 14: Economic viability of *gari* production with electric grater.

	Buy and Sell Modality	Fee-for-service Modality
NPV	$5,500	$2,900
IRR	73%	53%
Discounted Payback (years)	2.0	3.2

The economic viability of investing in an electric cassava grater will largely depend on the amount of cassava the *gari* production business owner can process. **Figure 52** shows that production volume is among the variables that, if changed, would produce significant impact on expected NPV. Other variables that significantly affect the viability of investing in an electric grater for *gari* production include the sale price, interest rate, and electricity price.

Figure 52: Production volume, sale price, electricity price and interest rate have the largest impact on expected returns for buy-and-sell *gari* processors.[lxiv]



[lxiv] Results are similar in the FFS modality, that production volume, electricity price, FFS charge are the main drivers for economic returns. We benchmarked model assumptions on sale price, FFS charge, and electricity price with multiple sources such as IFPRI APPEAL survey results and literature to make sure they are reasonable.

Based on surveys and sector expert interviews, it is highly likely that *gari* production business owners will be able to access the volumes of cassava needed to reach a break-even NPV (where NPV equals zero). **Figure 53** and **Figure 54** show that the volume of cassava that a *gari* processor needs to break even ranges from 670 to 720 tons per year depending whether he or she buys and sells *gari* or charges community members a fee for the processing service. Based on average farm sizes and yield numbers, these amounts correspond to the cassava production volumes of around 17 to 18 small-holder farmers.[lxv]

A processor with diesel grater in Alangkel community in Cross River

In the communities surveyed, a few hundred farmers in a community is common. In fact, our analysis suggests that there may be enough volume to satisfy multiple *gari* processing businesses in one community. The total annual yield in the median community in Cross River is around 28,300 tons per year, which could easily supply enough cassava for tens of processors in the community and allow them to break-even. However, the number of processors that a community can sustain will vary by location as production volumes vary. For example, community champions reported 8–2,000 cassava growers in their respective communities in Cross River in our survey. Based on this, it appears that most communities have more than the 20 farmers needed for a viable local *gari* production business.

[lxv] As discussed in **Appendix A.2.1**, on average small-holder farmers farm four hectares of cassava with yields of around 10 tons per hectare per year in Nigeria.

Figure 53: Buy and sell *Gari* processors can Break Even Processing Relatively Low Volumes.

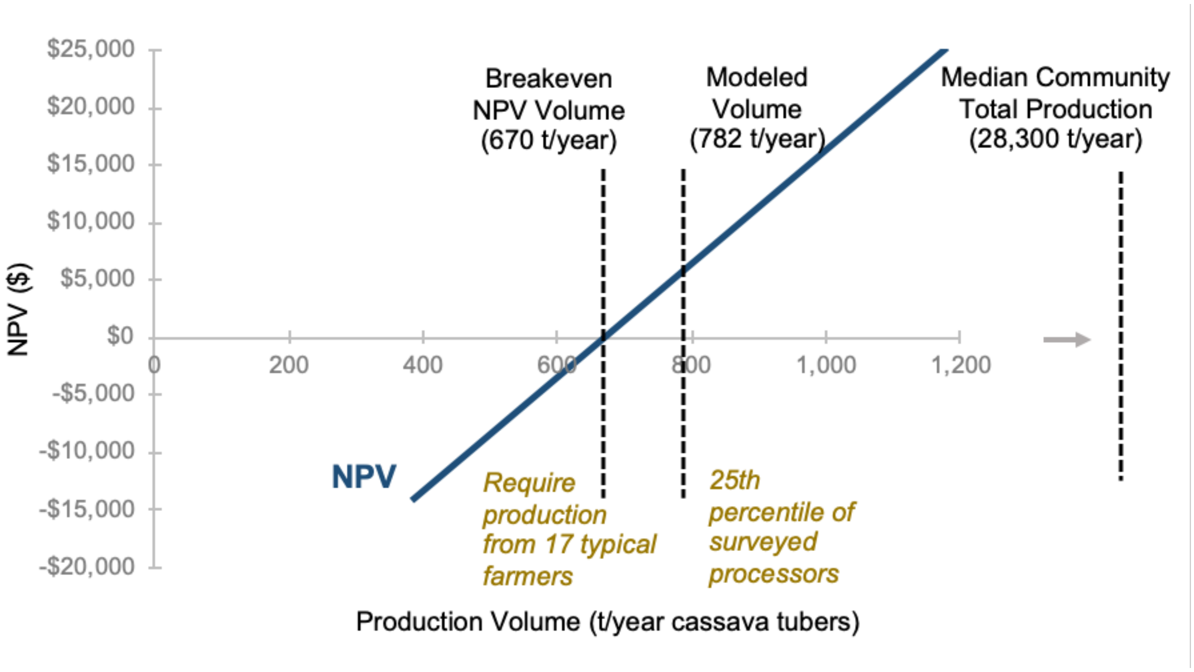
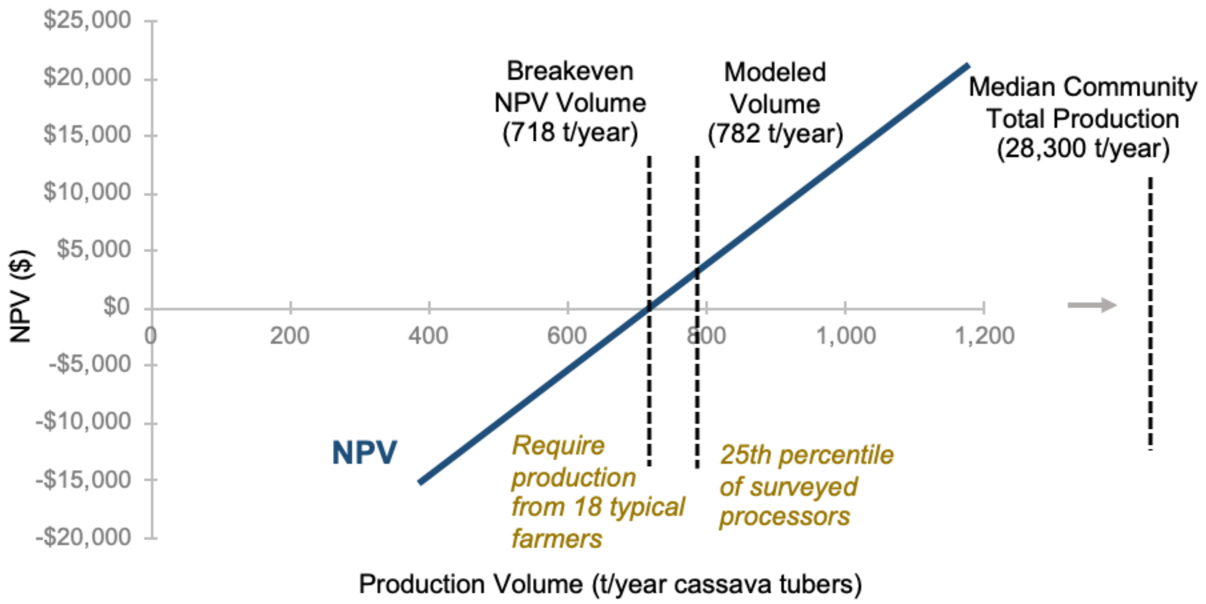
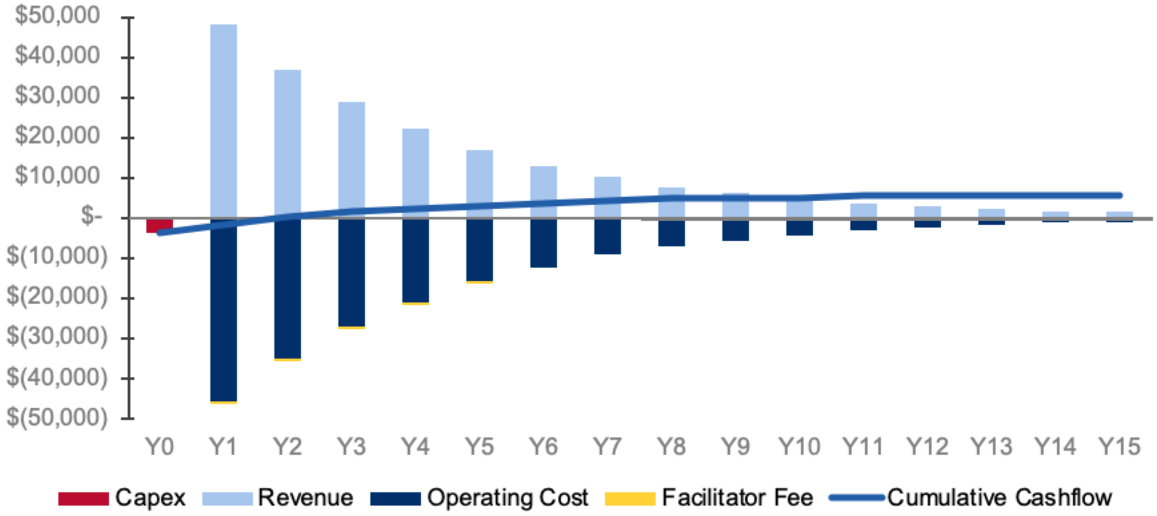


Figure 54: Fee-for-service *Gari* Processors can Break Even Processing Relatively Low Volumes.



Cassava processors we surveyed reported a wide range of daily processing volume data from 750–4,000 kg, and **to be conservative, we assume the 25th percentile as a baseline for analysis**. At this processing volume, the economic viability of investing in an electric grater is strong for both buy and sell and fee-for-service processors. As **Figure 55** shows, the NPV for the buy and sell processor investing in a new electric grater is around $5,500 and he or she is able to recover the investment in about two years. This type of processor captures additional value from value-add processing also from taking the trader role. It is possible that with an electric grater and improved processing efficiency, business owner can generate more revenue from reduced spoilage and increased yield. However, to be conservative, our analysis assumes yield and sale price remain the same as status quo. We find that savings on energy and maintenance cost alone can justify the switch to electricity even if the old grater has 10 years of remaining life.

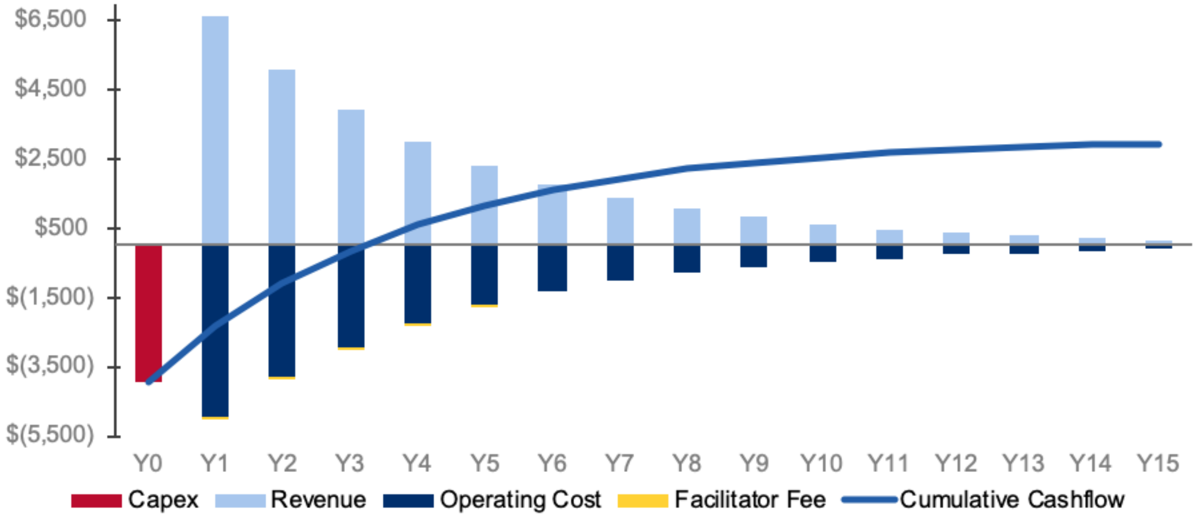
Figure 55: Buy and Sell: Discounted Cashflows of Electric Equipment Investment in *Gari* Production.



Performance indicator	Value
NPV	$5,500
IRR	73%
Discounted Payback	3.2 years

For business owners using a fee-for-service business modality, investing in an electric grater is less lucrative, but still shows strong economics with an NPV of $2,900 and discounted payback of about 3 years (**Figure 56**). Under the fee-for-service scenario, with the same conservative assumptions on yield, the only value accruing to the cassava processor of investing in the electric grater is the reduction in electricity and maintenance costs. Replacing an existing diesel grater, the investment may not be viable, depending on the remaining lifetime of the diesel grater, if their service charge is not adjusted.

Figure 56: Fee-for-service: Discounted Cashflows of Electric Equipment Investment in *Gari* Production.



Performance indicator	Value
NPV	$2,900
IRR	53%
Discounted Payback	3.2 years

Table 15 shows a list of the key crop-specific assumptions used in the analysis and source of data. See **Appendix C.1.2** for the methodology and overarching assumptions used.

Table 15: List of Key Assumptions Used in *Gari* Production Economic Feasibility Modeling.

	Assumption in Modeling	Source and Explanation
Seasonality	Not seasonal	All survey respondents reported cassava processing as not seasonal.
Sale price in Buy and Sell modality	$0.32/kg (*gari*)	Based on survey results while cross referencing literature review findings.
Raw material price in Buy and Sell modality	$0.068/kg (peeled cassava tubers)	Based on survey results from IFPRI APPEAL survey data.
Service charge in Fee-for-service modality	$0.011/kg (peeled cassava tubers)	Based on survey results while cross referencing literature review findings.
Current energy cost (fossil fuel)	$2,400/year	Based on survey results.
New energy cost (electricity)	$2,200/ year	Energy consumption is calculated based on equipment utilization rate and electricity tariff.
Non-energy cost	$4,300/year	This equals production volume times unit non-energy cost, which comes from literature review.

	Assumption in Modeling	Source and Explanation
Maintenance cost	$94/year	Based on survey results and a 50% maintenance saving using electric equipment.
Volume of cassava grated	782,100 kg/year	Based on survey results.
Equipment lifespan	15 years	Based on equipment analysis and expert interviews (e.g. FIIRO).
Yield increase (*gari*)	0%	No research strongly indicates that *gari* yield can improve with electric equipment.[lxvi]
Equipment cost	$1,100 for grater ($3,490 for whole process)	Equipment is selected to best match current processing volume. Specification from product catalogue.
Equipment capacity	5 kW	From product catalogue.
Equipment processing capacity	1,000kg/hour	From product catalogue.
Utilization rate	9%	Calculated based on equipment processing capacity and total production volume from survey.

C.3 *Economic Viability Analysis: Maize Flour Milling*

The fee-for-service sales modality is the predominant approach used by grain flour millers in the communities surveyed, with maize being the most common grain processed.

As **Table 16** shows, there is a positive and compelling economic case for investing in electric multi-purpose mills for maize flour milling. Maize flour millers can save over $800 per year on energy expenditures with an electric mill, recouping their investment in under two years and enjoying a high rate of return.

Table 16: Economic Viability of Maize Flour Milling.

	Fee-for-service Modality
NPV	$2,100
IRR	108%
Discounted Payback	1.3 years

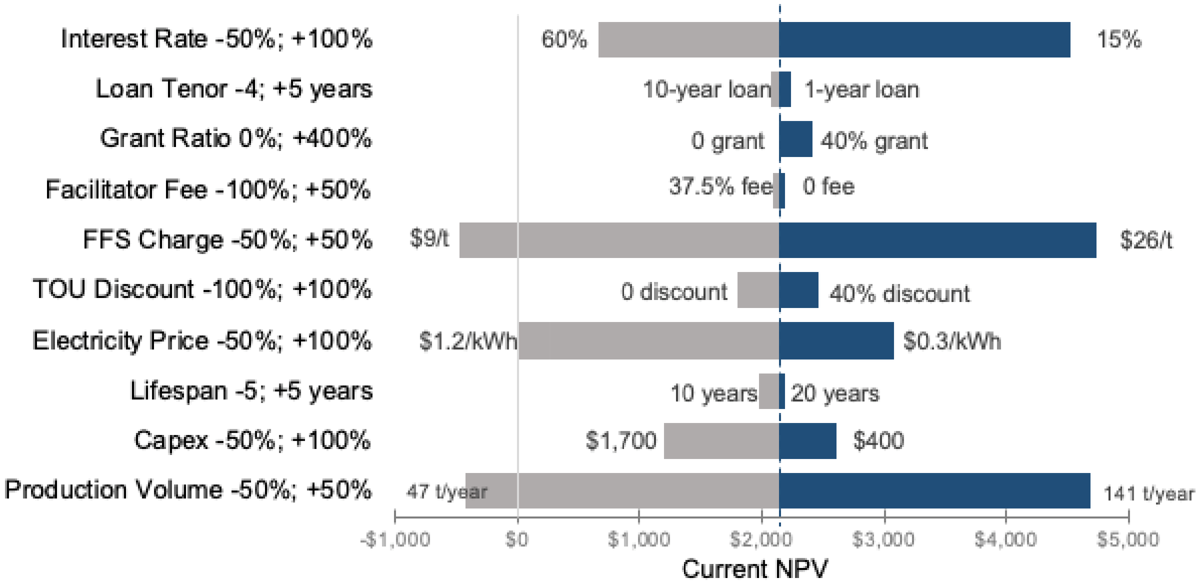
The economic viability of investing in an electric maize flour mill will depend on the amount of grain the mill owner can process. **Figure 57** shows that production

Processor with his maize flour mill in Kafari community in Kaduna.

[lxvi] In our analysis, the counterfactual is a mechanized process that uses fossil fuel. Electrifying the same equipment is not expected to result in significant change in throughput unless a larger machine is purchased

volume is one of the variables that if changed would produce the largest impact on expected NPV. Other variables that can significantly affect the financial results of investing in a grain flour mill include the FFS charge, electricity price and interest rate (see **Appendix C.1.3** for sensitivity analysis approach).

Figure 57: Production Volume, Electricity Price, and Sale Price have the Largest Impact on Expected Returns for Fee-for-service Maize Flour Miller.



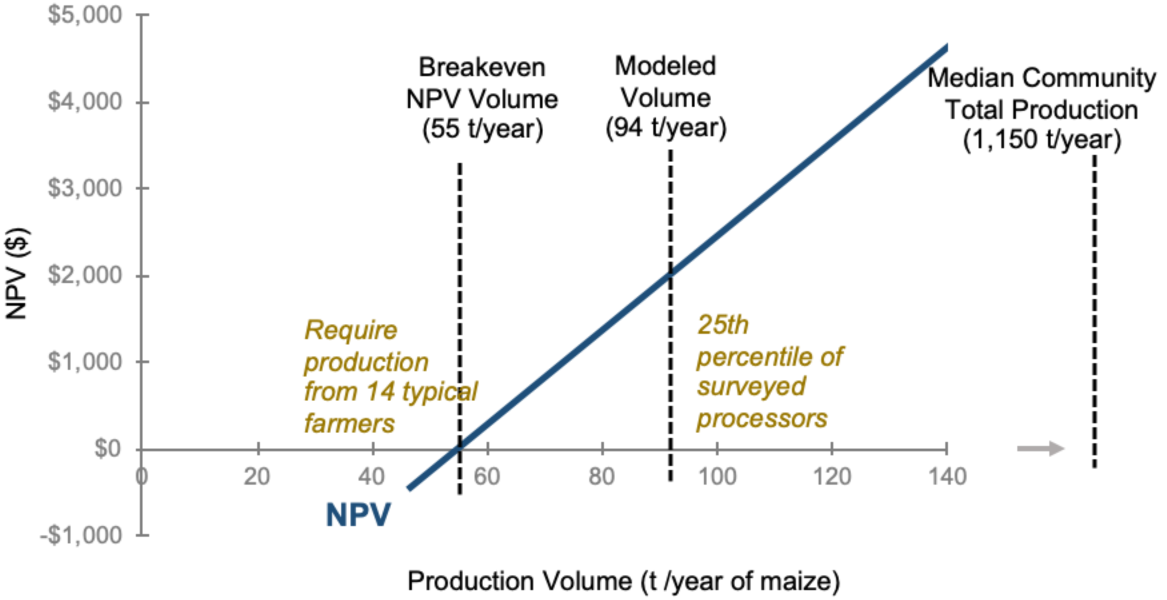
Accessing the minimum volume of maize required to achieve a break-even NPV (where NPV equals zero) does not appear problematic in appropriate rural Nigerian communities, and so the likelihood is high that electric maize flour mills will be economically viable investments**. Figure 58** shows that the volume of maize a miller needs to process in order to break even is about 55 tons per year. This amount of maize corresponds to the production volumes of around 14 small-holder farmers based on average farm sizes and yield numbers.[lxvii] Survey results show that that there are around 300 maize farmers in a median community in Kaduna. As such, it appears highly likely for a maize miller to be able to access the volumes of maize needed to break even.

This analysis suggests that there may be enough volume to satisfy multiple grain flour millers in one community. The total annual maize yield in the median community in Kaduna is around 1,140 tons per year, which could easily supply enough maize for a dozen maize millers in the community and allow them to break even.

However, the number of processors that a community can sustain will vary by location as production volumes vary. For instance, survey results find that there are about 1,000 maize farmers in one community in Cross River, who can harvest 4,000 tons maize per year. We also observe farming and consumption of other grains such as sorghum in the same community. These grains can be processed into grain flour using the same multi-purpose mill, representing additional milling demand for mill owners.

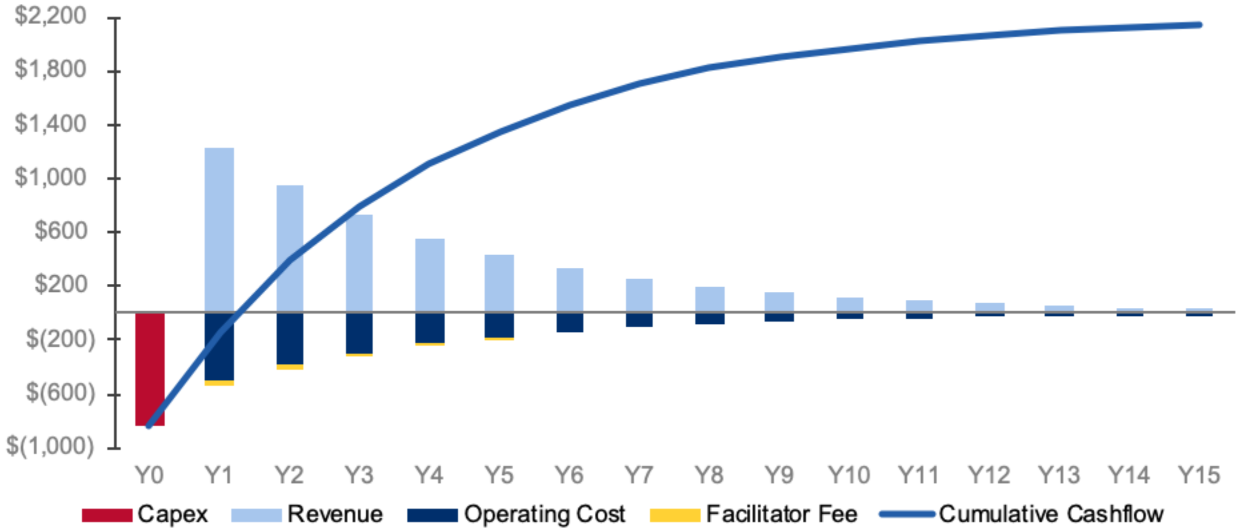
[lxvii] As discussed in **Appendix A.3.1**, on average small-holder farmers farm two hectares of maize with yields of around 2 tons per hectare per year.

Figure 58: Fee-for-service Maize Flour Milling: Maize Millers can Break Even Processing Relatively Low Volumes.



Survey responses show daily processing volumes ranging from 100–500 kg of maize. We **choose the volume corresponding to the 25th percentile as a conservative assumption**. At this processing volume, it is economically viable to invest in an electric mill. As **Figure 59** shows, the NPV for the maize processor investing in a new mill is around $2,100 with a discounted payback of less than two years.

Figure 59: Fee-for-service: Discounted Cashflows of Electric Equipment Investment in Maize Flour Milling.



Performance indicator	Value
NPV	$2,100
IRR	108%
Discounted Payback	1.3 years

Table 17 shows a list of the key crop-specific assumptions used in the analysis and sources of data. See **Appendix C.1.2** for the methodology and overarching assumptions used.

Table 17: List of key assumptions used in maize flour milling economic feasibility modeling.

	Assumption in Modeling	Source and Explanation
Seasonality	Not seasonal	All survey respondents reported grain flour milling as not seasonal.
Service charge in Fee-for-service modality	$0.017/kg (of maize, or sorghum and other grains)	Based on survey results.
Current energy cost (fossil fuel)	$1,400/year	Based on survey results.
New energy cost (electricity)	$600/ year	Energy consumption is calculated based on equipment utilization rate and electricity tariff.
Non-energy cost	$30/year	This equals production volume times unit non-energy cost, which comes from literature review.
Maintenance cost	$50/year	Based on survey results and a 50% savings in maintenance costs of using electric equipment
Volume of grain milled	93,900 kg/year	Based on survey results.
Equipment lifespan	15 years	Based on equipment analysis and expert interviews (e.g. FIIRO).
Yield increase (grain flour)	0%	No research strongly indicates that yield can improve with electric equipment. This study assumes a conservative assumption that throughput remains the same with electric equipment as it would with fossil-fuel powered equipment.
Equipment cost	$830	Equipment is selected to best match current processing volume. Specification from product catalogue.
Equipment capacity	3 kW	From product catalogue.
Equipment processing capacity	250kg/hour	From product catalogue.
Utilization rate	4%	Calculated based on equipment processing capacity and total production volume from survey.

C.4 *Economic Viability Analysis: Rice Milling*

There is a positive and compelling economic case for investing in electric rice mills, although performance varies depending on the sales modality selected.

As **Table 18** shows, at the processing volume indicated in the survey rice millers can generate a NPV of $8,800 and recover their investment within a year under the buy and sell modality. In contrast, under the fee-for-service modality, investing in an electric mill is not economically viable unless the rice miller can charge higher fees to recoup their investment.

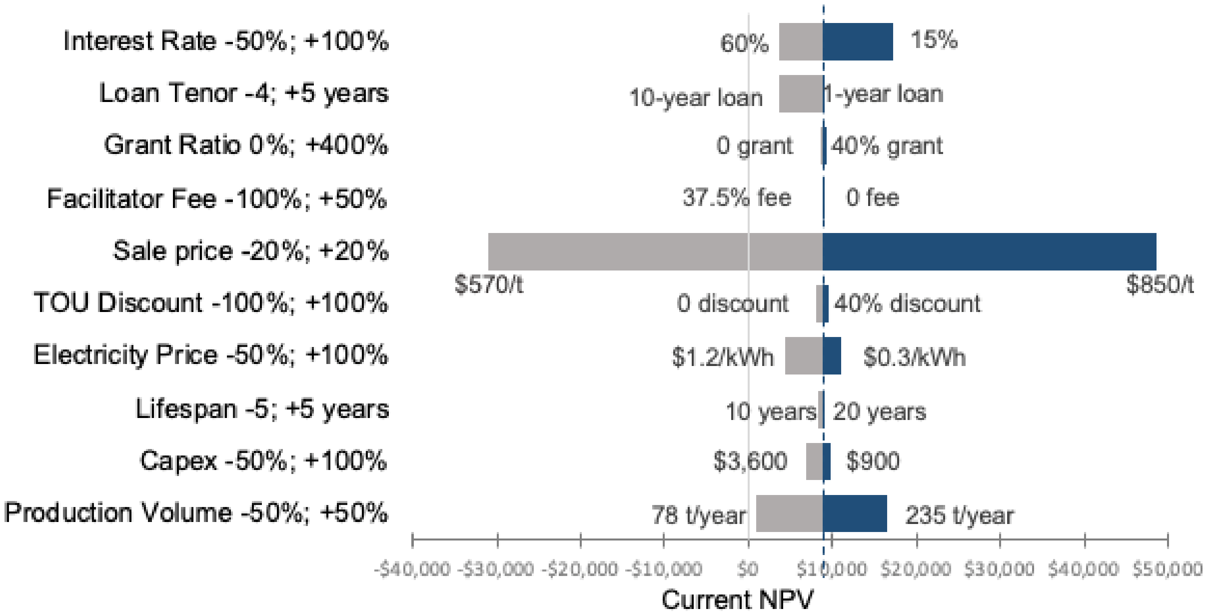
Rice processor with one-stage mill in Ijegu-Yachie community in Cross River

Table 18: Economic Viability of Rice Milling with Electric Mill.

	Buy and Sell Modality	Fee-for-service Modality
NPV	$8,800	-$600
IRR	179%	19%
Discounted Payback (years)	0.7	n/a

These positive results hinge on production volume. **Figure 60** shows that production volume is one of the variables that, if changed, would produce significant impact on expected NPV. Other variables that can significantly affect the financial results of investing in a rice mill include the sale price or FFS charge, interest rate, and electricity price (see **Appendix C.1.3** for sensitivity analysis approach).

Figure 60: Production Volume, Electricity Price, and Sale Price have the Largest Impact on Expected Returns for Buy-and-Sell Rice Millers[lxviii]



It appears feasible for a rice miller to access the minimum volume of threshed paddy rice required to achieve a break-even NPV (where NPV equals zero), and the likelihood is high that investing in an electric rice mill is economically viable. **Figure 61** and **Figure 62** show that the volume of threshed or parboiled paddy rice that a rice miller needs to process in order to break even ranges from 70 to 160 tons per year depending whether he or she buys and sells milled rice or charges community members for fee-for-service.

Based on average farm sizes and yield numbers, these amounts of threshed paddy rice correspond to the production volumes of around 14 to 34 small-holder farmers.[lxix] We find that there are around 250 farmers in the community in Kaduna with the median number of rice farmers ('median community'). As such, it appears highly likely for a rice miller to be able to access the volumes of threshed paddy rice needed to break even.

In fact, our analysis suggests that there may be enough volume to satisfy multiple rice millers in one community. Survey results show that the total annual rice yield in the median community in Kaduna is around 1,375 tons per year, which could easily supply enough threshed paddy rice for at least two to three rice millers in the community and allow them to break even.

However, the number of processors that a community can sustain will vary by location as production volumes vary. For instance, survey results find that yields in Cross River can be as high as 6,075 t/year with 1,350 farmers farming in one community.

[lxviii] Results are similar for FFS millers: production volume, electricity price, FFS charge are the main drivers for economic returns. Model assumptions on sale price, FFS charge, and electricity price were benchmarked against multiple sources such as IFPRI APPEAL survey results and literature review to ensure assumptions are reasonable.

[lxix] As discussed in **Appendix A.4.1**, on average small-holder farmers farm three hectares of rice with yields of around 1.7 tons per hectare per year in Kaduna, and four hectares of rice with yields of around 2.2 tons per hectare per year in Cross River.

Figure 61: Buy and sell Rice Milling: Rice millers can Break Even Processing Relatively Low Volumes.

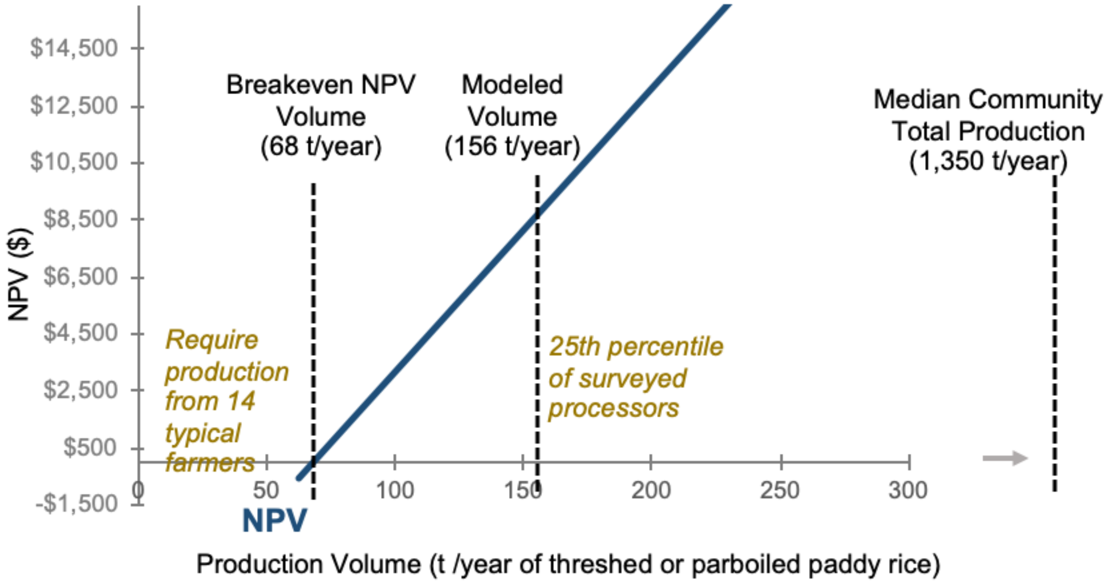
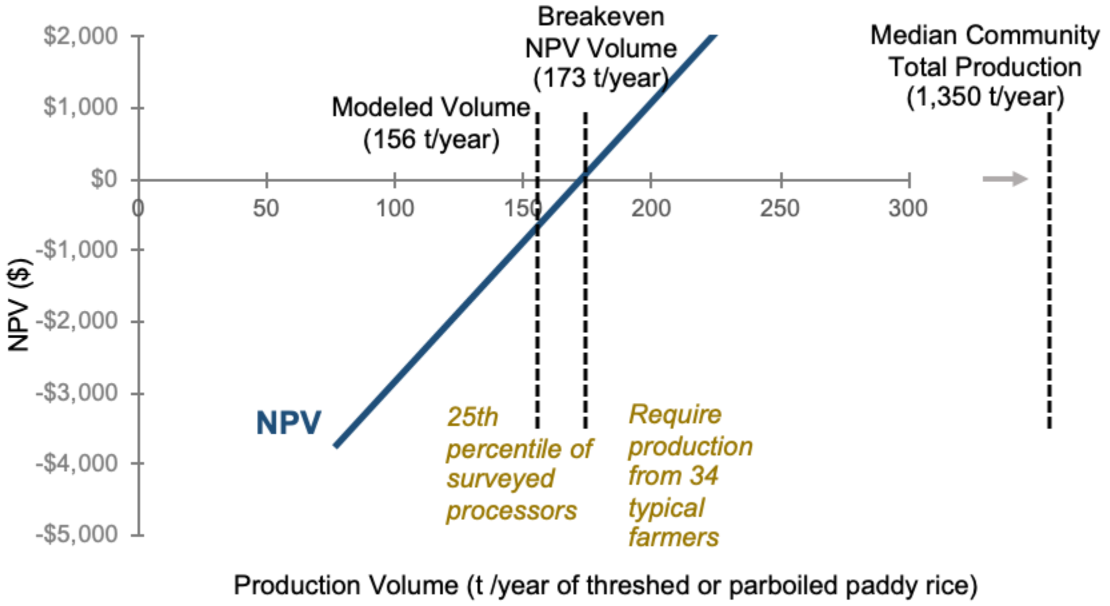
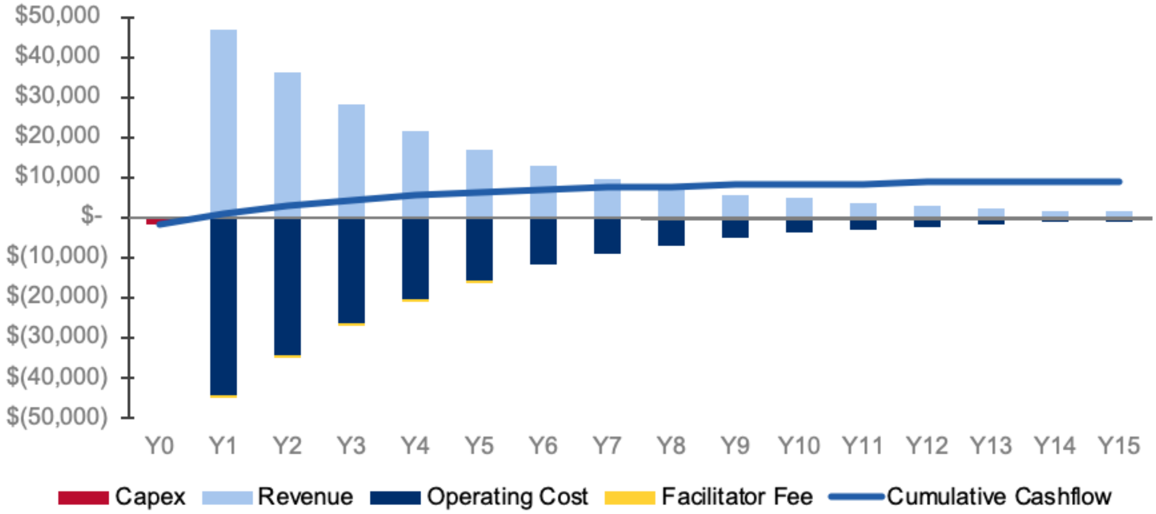


Figure 62: Fee-for-service Rice Milling: Rice Millers Can Break Even Processing Relatively Low Volumes.



Surveys conducted with rice millers indicate much higher production volumes than those assessed in the break-even analysis, suggesting strong returns. Survey responses show a wide range in daily processing volumes of threshed or parboiled paddy rice and **we choose the volume corresponding to the 25th percentile as a conservative assumption**. At this processing volume, the economic viability of investing in electric rice mills is strong for rice millers operating under the buy and sell scenario. As **Figure 63** shows, the NPV for the rice miller that is investing in a new two-stage rice mill is around $8,800 and the rice miller is able to recover his or her investment in less than a year. Under the buy and sell scenario the rice miller captures a portion of the trader's value of selling milled rice. Specifically, a key benefit of investing on a two-stage rice mill is that the new mill breaks fewer rice grains and generates fewer losses than the one-stage "Engelberg" rice mill typically used today (see **Appendix A.4.3**). Under the buy and sell scenario the rice miller can capitalize on the improved quality of the production process.

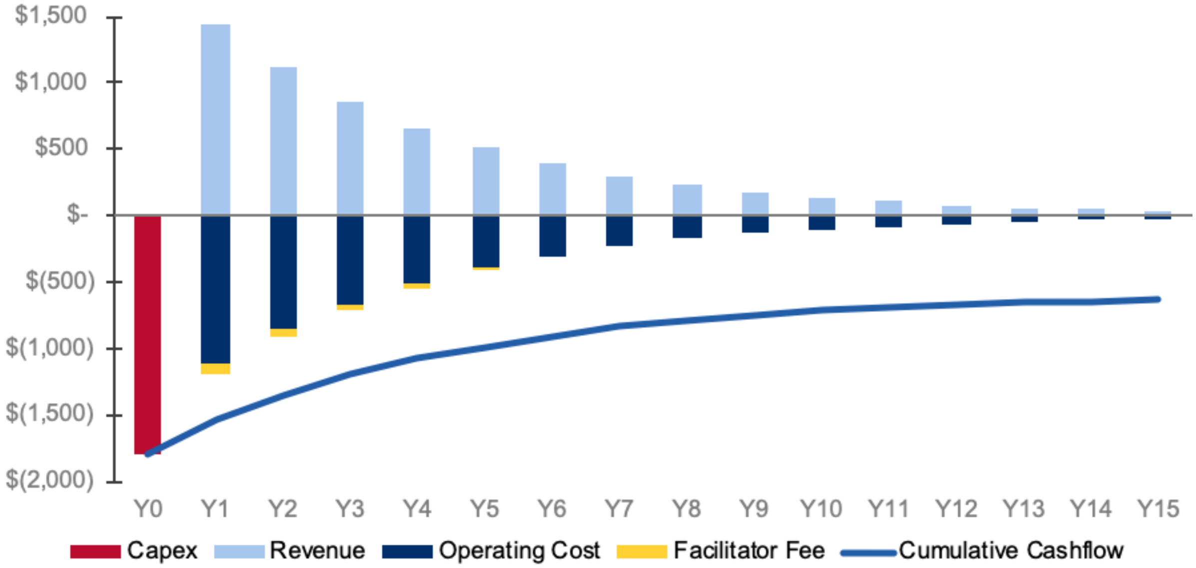
Figure 63: Buy and Sell: Discounted Cashflows of Electric Equipment Investment in Rice Milling.



Performance indicator	Value
NPV	$8,800
IRR	179%
Discounted Payback	0.7 year

For the rice miller operating a Fee-for-service modality, buying a new two-stage rice-mill would have a negative NPV of around -$600 (**Figure 64**). Unless the rice miller can adjust the fee charged to reflect the new value the electric two-stage rice mill generates in higher yields and better-quality milled rice, the rice miller will be unable to recover his or her investment.

Figure 64: Fee-for-service: Discounted Cashflows of Electric Equipment Investment in Rice Milling.



Performance indicator	Value
NPV	-$600
IRR	19%
Discounted Payback	n/a

Table 19 shows a list of the key crop-specific assumptions used in the analysis and sources of data. See **Appendix C.1.2** for the methodology and overarching assumptions used.

Table 19: List of Key Assumptions Used in Rice Milling Economic Feasibility Modeling.

	Assumption in Modeling	Source and Explanation
Seasonality	Not seasonal	All survey respondents reported rice milling as not seasonal.
Sale price in Buy and Sell modality	$0.71/kg (milled rice)	Based on survey results while cross referencing literature review findings.
Raw material price in Buy and Sell modality	$0.36/kg (threshed or parboiled rice paddy)	Based on survey results from IFPRI APPEAL survey data.
Service charge in Fee-for-service modality	$0.012/kg (threshed or parboiled rice paddy)	Based on survey results while cross referencing literature review findings.
Current energy cost (fossil fuel)	$900/year	Based on survey results.
New energy cost (electricity)	$900/ year	Energy consumption is calculated based on equipment utilization rate and electricity tariff.
Non-energy cost	$500/year	Calculated as a percentage of energy cost based on literature review.
Maintenance cost	$80/year	Based on survey results and a 50% maintenance saving using electric equipment.
Volume of rice milled	156,400 kg/year	Based on survey results.
Equipment lifespan	15 years	Based on equipment analysis and expert interviews (e.g. FIIRO).
Yield increase (*milled rice production*)	10%	Research shows that a two-stage mill reduce loss compared to a single-stage mill typically used today.
Equipment cost	$1,800	Equipment is selected to best match current processing volume. Specification from product catalogue.
Equipment capacity	11 kW	From product catalogue.
Equipment processing capacity	1,000kg/hour	From product catalogue.
Utilization rate	2%	Calculated based on equipment processing capacity and total production volume from survey.

APPENDIX D BUSINESS MODEL OPTIONS

This appendix explores key business models presented in **Section 5** further. We present the **Facilitator Model** in **Appendix D.1** and the **Processing Center Model** in **Appendix D.2** and cover the following content areas:

- **Model overview**—introduces the model, illustrates the roles of the actors and relationships that exist between them, and explains the value proposition each actor derives from participating in the model.
- **Case study**—expands upon the roles, relationships, and examples described in **Section 4**
- **Setting the model in context**— provides examples of similar models to place the model in context of similar approaches that have been tested before and reference organizations that could be consulted to share lessons learned.
- **Roles and responsibilities**— lists each actor's responsibilities and the characteristics they must possess as a first step towards making partnering decisions.
- **Model performance**—shows how the model performs against the key criteria to help the user determine when the model is appropriate and defines a set of actions for mitigating risks and addressing barriers that the user may face in implementing the model and that the deployment strategy should consider.

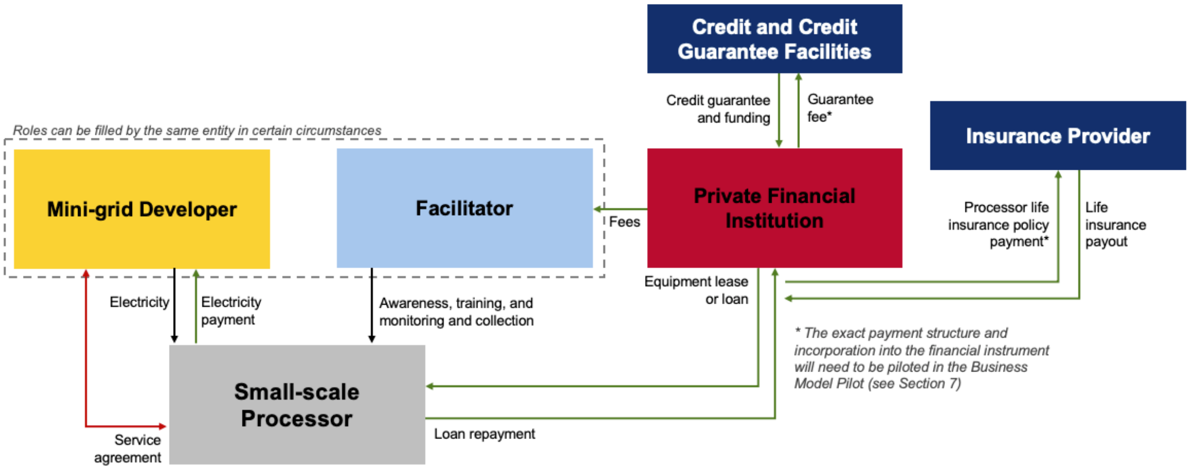
We also present an overview of the Offtaker-Based Model **in Appendix D.3**. We do not explore the Offtaker-Based Model in as much depth as we do the other models, because given the additional complexity and cost compared to other models, the Offtaker-Based Model is not considered suitable for the Tier 1 and 2 activities prioritized in **Section 3.** However, the Offtaker-Based Model has significant potential for several Tier 3 activities and so we present an overview of the Offtaker-Based Model in this appendix for future consideration.

D.1 *Facilitator Model Overview*

The Facilitator Model is appropriate for Tier 1 activities prevalent in rural communities (cassava grating, rice milling, and general flour and meal milling). The model would not displace local small-scale processors already participating in the sector and uses a straightforward design that addresses the primary barriers faced by local processors who are already carrying out Tier 1 activities in these rural communities. Since there are limited barriers to entry for these activities, the Facilitator Model instead focuses on addressing the barriers that prevent greater participation and a switch to electric equipment. Survey results suggest that access to credit is the main barrier preventing greater participation in Tier 1 activities (see **Section 5.1**).

Figure 65 illustrates the institutional arrangements—the roles of and relationships between actors—of the Facilitator Model. A key difference of the Facilitator Model compared to the Processing Center Model is that the small-scale processor is ultimately responsible for the credit and operational risk. That is, the small-scale processor invests and owns the electric equipment and is responsible for repaying the loan and operating the electric equipment. In an initial phase, a facilitator connects the small-scale processor to other actors in the model, building awareness about the investment opportunity and providing business development training to support loan applications and equipment selection. Once the viability of lending to small-scale processors is proven, the role of the facilitator is phased out and the private financial institution (PFI) assumes the role of identifying and selecting would-be processors. Deployment will require additional actors to provide funding and overcome financial barriers, as described in **Section 6.3.**

Figure 65: Institutional Arrangements of the Facilitator Model.[lxx]



A key value proposition of the Facilitator Model is that the small-scale processor owns the equipment and so earns a greater portion of the value addition captured from investing in electrical equipment. The small-scale processors achieve returns of up to 180 percent by investing in new equipment (see **Section 4).** Nonetheless, each actor receives value from participating in the Facilitator Model. The mini-grid developer may push down the cost recovery tariff allowing them to capture additional customers in the community **(see Section 4.2**). The facilitator can earn fees of up to four percent of the capital investment (equipment purchase) see **Appendix E-3.** Lastly, the PFI can increase its agricultural loan portfolio.

D.1.1 Case Study

In this section we expand on the content included in **Section 5.2** to clarify the reader's understanding of the model by describing an example where we identify potential candidates that could fulfill the roles embedded in the model. Notably, the example is meant to be illustrative of the relationships that may exist between the actors and the characteristics the actors should possess and does not signify that any organization mentioned has committed to participating in implementing the model. We focus on describing the actors that are unique to the Facilitator Model: the facilitator, the small-scale processor, the PFI, and the mini-grid developer. The credit facility is common across both models and we describe it in **Section 6.3.**

- **Small-scale processor** invests in electric equipment and is responsible for operating the equipment and repaying the equipment loan. The small-scale processor is a local entrepreneur that already invests in processing for sale in local markets and first-time buyers of electric equipment. Small-scale processors in agrarian communities are often also small-holder farmers that process their own crops and those of other community members. **Box D-1** presents a profile of a small-scale processor in Cross River and illustrates an example of the small-scale processors that could fulfill this role in the Facilitator Model.

[lxx] **Figure 67** shows an equipment lease to the small-scale processor. But, the specific type of financial product can also include loans. The key is that the facilitator provides the small-scale processor the equipment and not cash. This will reduce credit risk and make equipment selection and deployment more straightforward.

Box D-1—Profile of a small-scale processor in a rural community

Idu Samon Idagu (pictured above) owns and operates a small rice milling business in Akreha, an unelectrified rural community of around 1,500 households in Yala, Cross River. Also pictured is the diesel-run rice mill he owns and uses to process parboiled paddy rice into milled rice. His small business has two revenue streams: he purchases parboiled paddy rice and sells the milled rice and charges a fee for processing the parboiled paddy rice produced by other community members. He also keeps around 30 percent of the total milled rice he processes for his household's consumption. He processes around 1,500 kgs of parboiled paddy rice and earns approximately N78,000 during a busy week. He would like to expand his processing capacity but lacks access to credit to purchase new equipment and would want training in business development before investing.

Idu is not alone. There are three other small-scale rice millers operating in his community alone and enough candidates fit Idu's profile to justify existing interventions targeting partners like him. The Deutsche Gesellschaft für Internationale Zusammenarbeit Competitive African Rice Initiative (GIZ CARI) established the Farmer Business School in FCT, Kaduna, Niger, Kano, Kebbi, and Jigawa to provide business training and input support to farmers and small-scale processors like Idu. The Farmer Business School has trained 74,100 small-holder farmers, organizing them into groups and graduating participants through different levels of maturity ranging from the first level where participants access pre-financed inputs and training for increasing cultivation productivity up to advanced groups that provide business development support and connect participants with financial institutions to finance threshers and mills. Examples exist of groups that have gone through the three levels of training and financing and have obtained commercial bank loans to finance equipment purchases. These are the local entrepreneurs based in local communities that the Facilitator Model would target for financing electric equipment purchases.

Source: Survey data. Competitive African Rice Initiative (CARI) Empowering small-scale farmers in Sub-Saharan Africa, 2018

- **Facilitator** leverages its local presence and relationships to connect small-scale processors to finance and equipment access. The facilitator informs small-scale processors about the opportunity to invest in electric equipment. They also act as a conduit between the PFI and the small-scale processor, supporting with training on business development and loan applications, selecting the right equipment, and collecting loans.[lxxi] The candidate that fulfills the facilitator role must have experience selling a service or product and collecting payments in farmer communities and so have required knowledge to vet and select small-scale processors who could be good candidates to receive loans.

  Organizations that can fulfill the facilitator role need to be embedded in farmer communities and have an operational model that aligns with this role. For instance, an organization like Solar Sisters which specializes on selling and distributing solar equipment in un or under-served communities, has an operational model that aligns with the facilitator role. Solar Sisters partner with a network of locally based community members that leverage their ties and relationships to community members to sell equipment for a commission.

  For the Facilitator Model to work, the facilitators and equipment vendors also need to connect to ensure delivery of the equipment to these communities. The Association for Nigerian Fabricators (AMEFAN) has a network of equipment providers active across Nigeria that could serve as a conduit to connecting with active and reputable vendors serving mini-grid sites. AMEFAN aims to promote the production of equipment to agreed standards and specifications by members and so could also work to ensure that the equipment provided meets specifications required to connect to mini-grid systems. In communities served by social lenders like Babban Gona or One Acre Fund, the facilitator could also partner to use the social lender's distribution system used to deliver inputs to also deliver equipment for a fee.

- **Private finance institution** (PFI) on-lends funding from the credit facility to the small-scale processor by either leasing equipment that the small-scale processor pays to own or providing a loan (see **Section 6.1** and **Appendix E** for more information on the credit facility and other interventions to de-risk financing by the PFI).The PFI should have experience lending to the agriculture sector and have a mandate to support financial inclusion. PFIs that are already lending to the small-holder agriculture sector will have a better understanding of the risks prevalent in the sector, have developed mechanisms to address these risks, and be more willing to lend to small-scale processors. See **Section 6.3** where we explore the characteristics PFIs must possess and candidates that could fulfill this role in further detail

- **Mini-grid developer** serves a limited role under the Facilitator Model, focusing on its main business line of producing and selling electricity. As such, candidates suitable for participating in this model are those that have limited additional management capacity to assign to manage a new business line or would prefer to not diversify their business. We found that it is not uncommon to find examples of mini-grid developers, both among early entrants and mature mini-grid developers, that prefer a business model where they do not need to absorb additional operational responsibility and investment functions beyond their main business line.

Simpler service delivery methods exist for the Facilitator Model that may be appropriate depending on which actors are present in the community. For instance, the role of the facilitator can be carried out by the mini-grid developer in communities where an organization that can carry out the full responsibilities of the facilitator is not present. Specifically, the equipment vendor or PFI could provide credit to the small-scale processor and the mini-grid developer could collect payments, raise awareness, and makes connections with small-scale processors. This alternative service delivery method leverages the mini-grid

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[lxxi] It would not be necessary for the facilitator to collect loans for the PFI in communities where a MFI lends in as the MFI would carry out this responsibility.

developers' existing operations without transferring additional credit and operational risk since some mini-grid developers are tightly embedded in local communities and already collect payments from customers. However, various mini-grid developers we spoke to strongly prefer to not invest and operate a new business line and where feasible would prefer a Facilitator Model. Maintaining this separation on who carries the operational and credit risk under the Facilitator Model is important to finding a model suitable to the varied developer preferences.

D.1.2 Setting the Facilitator Model in Context

Similar approaches to the Facilitator Model have been tested before with developer-led appliance financing programs, where the mini-grid developer fulfills the role of the facilitator. Successful examples of this approach exist, but this variation places a significant operational burden and credit risk on the mini-grid developer—the developer must be willing and able to absorb this added burden. High performing mini-grid companies may have the appetite to diversify their business, but this is not the norm given the industry's early stage of development. Most mini-grid companies are focusing on managing the complexity of running a utility and do not necessarily have the additional management capacity to operate a new business line, especially without tools to mitigate credit risk. A Nigerian mini-grid developer with an existing appliance financing program and numerous sites stated:

> *"…although there isn't a big difference between appliance financing and financing equipment for productive use, we prefer to focus on our core competence…our first choice would be the Facilitator Model."*

In 2016, Jumeme partnered with Energy 4 Impact in Tanzania to develop a pilot project to provide financing to customers that could not afford to purchase electric equipment. To address this lack of access to credit Jumeme provided financing to small-scale entrepreneurs for equipment purchases and Energy 4 Impact provided training on business development and loan applications. The pilot program targeted 12 businesses and repayment rates were high. There are also examples of mini-grid developers offering appliance financing programs in Nigeria. For instance, GVE has an appliance financing program for residential use appliances like televisions, blenders, and refrigerators. These and other examples can be used to guide, provide lessons learned, and refine the Facilitator Model in new implementation efforts.

D.1.3 Roles and Responsibilities

Under the Facilitator Model, the facilitator carries out the most important role because it is responsible for identifying and obtaining buy-in from small-scale processors. To fulfill this role the facilitator needs to be able to leverage existing relationships to secure buy-in and do an initial screening of applicants. Additionally, if the PFI is not active in a specific community, the facilitator may have to monitor and collect loan repayments for the PFI and would need to have the management capacity to do so. These characteristics and the related responsibilities for the facilitator and other roles are shown in **Table 20.**

Table 20: Roles and Responsibilities in the Facilitator Model.

Role	Responsibility	Characteristics
Facilitator (Training and Awareness)	• Identify and vet would-be small-scale processors for loan applications • Train and advise small-scale processors on business plan development, equipment selection and purchases, and loan applications • Train and advise small-scale processors on production, and using equipment	• Embedded in and possessing deep knowledge of agrarian communities to identify reliable and capable small-scale processors to work with • Technical expertise to advise on equipment use and production

Role	Responsibility	Characteristics
	• Oversee production to monitor risks and, if necessary, collect payments from small-scale processors	• Proven and reputable institution to gain trust of PFI • Experience collecting payments from small-scale entrepreneurs
Small-scale processor (Equipment purchaser and operator)	• Invest in equipment • Apply for equipment loan or lease • Carry out production and market product • Make loan repayments or lease payments	• Local entrepreneurs receiving extension services and possessing track record of repayment of loans for agricultural inputs and services. See **Box D-1**
PFI (Funder and loan provider)	• Assesses loan applications from small-scale processor, screens applications, and disburses financing • Monitors loan portfolio and collects loan repayments, either from facilitator or directly from small-scale processor	• Experience lending to the agriculture sector, in activities connected to the cultivation segment • Mandate to support financial inclusion • For further detail see **Section 6.3**
Mini-grid developer (Electricity provider)	• Design and provide an appropriate tariff for customers engaged in agriculture productive use • Deliver reliable and sufficient power at agreed upon times and tariff, and complying with other terms of the Service Agreement • Advise on equipment specification to ensure equipment compatibility with mini-grid system • Collect electricity payments	• Proven and reputable company with ability to offer reliable and sufficient power at agreed upon tariff

Defining the supply and maintenance of equipment in the Nigerian market was out of scope for this study. Nonetheless the Map of Key Stakeholders (see **Appendix F**) found there are a significant number of vendors and fabricators producing the equipment needed to develop Tier 1 opportunities. The facilitator would work with these vendors to coordinate the delivery of equipment and maintenance.

Although our streamlined analysis showed that most of the equipment available are petrol or diesel powered due to existing demand patterns in rural areas, fabricators state they can swap in electrical motors easily. Further work is needed to test and define the compatibility of existing equipment to operator and patron preferences and mini-grid (see **Section 7**). Agricultural Development Programmes (ADPs) in collaboration with AMEFAN and national research institutes such as the and Federal Institute of Industrial Research (FIIRO) may be able to partner to test whether electric equipment that is available meets user needs and are compatible with mini-grid systems. AMEFAN can then standardize the agreed specifications among its network of member vendors.

D.1.4 Model Performance

Table 21*:* shows the Facilitator Model's performance against key criteria. The Facilitator Model meets most of the key criteria except for defining access to market. This means that the Facilitator Model is suitable in most communities where the market and local capacity is proven and where facilitators are present who can connect small-scale processor to financing.

Table 21: Facilitator Model Performance Relative to Criteria and Barriers to Implementation.

Performance Criteria	Performance
Access to credit	✓
Access to market	✗
Awareness and education	✓
Incentives for reliable electricity access	✓
Inter-actor trust	✓
Burden on mini-grid developer	✓
Complexity	Medium
Scalability	Medium

Access to credit—lack of access to credit is the major barrier for small-scale processors to purchase electric equipment. The Facilitator Model embeds financing and de-risking instruments linking small-scale processors with finance providers to reduce this barrier.

The small-scale processor who receives financing under the Facilitator Model lacks a credit history and collateral that PFIs require to provide financing. Under the Facilitator Model, the PFI holds the credit risk. The Facilitator Model will require partnering with PFIs that are already lending in the agriculture sector and have a mandate to support financial inclusion. PFIs fulfilling these criteria would know how to assess and address crop risk and would also be more comfortable in lending to micro and small business owners. However, the limited prevalence of these types of institutions in the communities we surveyed suggests that PFIs require de-risking to expand their loan portfolio in these communities. The partial credit risk guarantee transfers some of the credit risk from the PFIs to the credit guarantee facility that can better manage this risk. The Facilitator Model also includes life insurance to protect against sickness or death that affect the small-scale processors' ability to repay their loans.

Access to market—the Facilitator Model is suitable for Tier 1 activities producing products that are prevalently bought and sold in rural communities. The Facilitator Model does not embed market linkages in its design, and this limits the model's suitability to larger communities that have significant commercial activity. However, field surveys show that there is significant commercial activity in mini-grid communities for the products produced for Tier 1 (see **Section 3).**

Awareness and education—under the Facilitator Model the role of the facilitator addresses this barrier. As described in **Appendix D.1.3** is responsible for awareness-raising and capacity building. The facilitator works with small-scale processors to raise awareness about the opportunity to access loans for equipment purchases and provides capacity building to connect small-scale processors to loans. The facilitator also trains small-scale processors on quality standards, production processes, and proper equipment use.

The facilitator also serves as a liaison ensuring that information flows between actors making decisions. For example, the facilitator connects with the mini-grid developer to identify compatible equipment. If equipment redesign is needed to ensure compatibility of electric equipment with user needs and mini-grid systems, the facilitator can work with ADPs and other relevant agencies to define user needs and test equipment.

Incentives for reliable electricity access—the design of the Facilitator Model includes a Service Agreement that addresses this barrier by aligning expectations between the mini-grid developer and small-scale processors. Specifically, the Service Agreement aligns the mini-grid developer and small-scale processors on their responsibilities and commitments needed for a mutually beneficial relationship. For example, key commitments to agree on and that should be included in the Service Agreement include the expected level of service, equipment specifications, tariffs, and the payment process. Selecting a reputable mini-grid developer with track record of providing reliable service and introducing the mini-grid developer early in the process to advise on equipment selection could improve how the model performs against this criterion during implementation.

Interactor trust—the Facilitator Model includes the facilitator to connect and coordinate actors. The candidates selected to fulfill the facilitator role need to be trusted organizations embedded in local communities with established relationships with small-scale processors.

Burden on mini-grid developer the variation of the Facilitator Model presented in this discussion does not impose additional operational burdens and risks on the mini-grid developer beyond those of providing reliable electricity service. However, variations of the Facilitator Model where the mini-grid developer carries out portions of the facilitator role may score worse on this criterion.

Complexity—the Facilitator Model requires embedding a facilitator and developing a Service Agreement which are not present in the simplest model we consider (see Processing Center Model). As a result, the Facilitator Model has a medium level of complexity. The additional agreement and actor required to implement the Facilitator Model increase the transactional costs of deploying the model, at least during the initial implementation when partners need to be identified, agreements are developed, and when the role of the facilitator is necessary before it can be phased out.

Scalability— the Facilitator Model requires selecting the right community that can provide the following two conditions:

- As discussed under the access to market criterion, the community should have ready access to a market to ensure the sale of the product. Establishing the market linkage is exogenous to the design of this model
- The community must have a reputable organization that can vet and identify small-scale processors to serve as a facilitator. In the absence of an organization willing to take this role, the Facilitator Model would require a mini-grid developer with enough experience operating in the community to carry out initial screening and partnering with a vendor provider to supply the equipment.

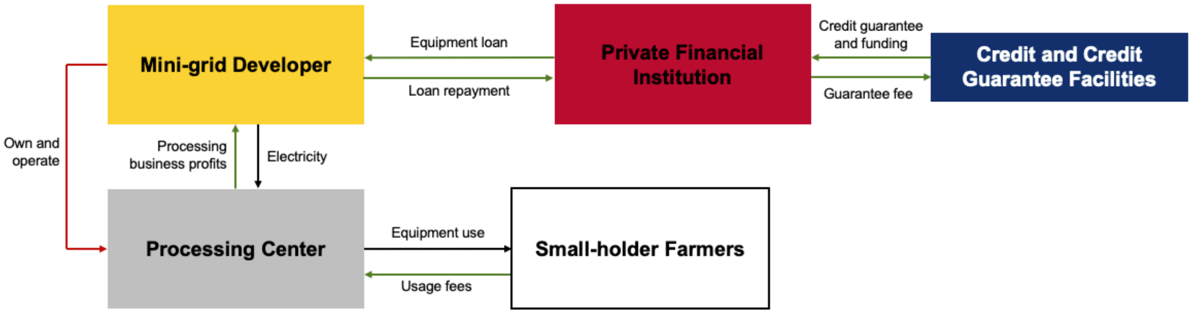
Compared to the Processing Center Model, the Facilitator Model requires an additional enabling condition which may reduce the number of communities that are suitable. As such, the Facilitator Model has a medium level of scalability. However, communities that meet these conditions exist. For example, Solar Sisters operates a network of partner entrepreneurs in communities in over 20 states across all geo-political zones in Nigeria.[lxxii] These communities may overlap with mini-grid suitable communities.

D.2 *Processing Center Model*

The Processing Center Model is appropriate for activities where there is proven demand for the product, but the activity is not prevalent in local communities. Using these criteria to determine when the Processing Center Model is appropriate can ensure that local entrepreneurs are not displaced by the mini-grid developer. These criteria can be more commonly found in processes that pre-process or conserve the purity and integrity of the crop and where investment is a barrier to entry for small-scale processors. Currently, threshing that can be centralized in the town center and multi-purpose drying meet these criteria. This is because these activities require a larger investment in equipment and facilities compared to investments needed for Tier 1 activities. This larger investment represents a barrier to entry that prevents small-scale processors from affording the equipment. In contrast, the mini-grid developer may face lower investment costs because it can use its existing power source and buildings to carry out the new business line.

Figure 66 illustrates the institutional arrangements —the roles of and relationships between actors—of the Processing Center Model. Under the Processing Center Model, the mini-grid developer is ultimately responsible for the credit and operational risk. The mini-grid developer invests in and owns the equipment and either charges the farmers usage fees to use the equipment or sells pre-processed product to an offtaker. Unlike the Facilitator Model, the Processing Center Model does not have a facilitator and the PFI lends directly to the equipment purchaser. Deployment will require additional actors to provide funding and overcome financial barriers, as described in **Section 6**.

Figure 66: Institutional Arrangements of the Processing Center Model



Compared to the Facilitator Model, the small-scale processors earn a smaller proportion of the value addition captured under the Processing Center Model. But as long as the mini-grid developer invests in activities that are not already prevalent in rural communities or if it does so, partners with small-scale processors, the Processing Center Model can generate additional value for all actors involved.

The mini-grid developer would gain an additional revenue stream to support its electricity sales. Depending on the usage patterns of the activity, the new activity may reduce the mini-grid developer's cost recovery tariff and help attract additional customers in the community.[lxxiii] The community receives

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[lxxii] Solar Sisters website: https://solarsister.org/what-we-do/our-impact/

[lxxiii] The analysis to solidify this hypothesis was outside the scope of this study—our analysis of mini-grid economics was limited to Tier 1 activities. Further study is required to support this statement.

a new service offered in their community, potentially reducing transportation costs if travel was required to obtain this service before. The PFI would receive the same value captured under the Facilitator Model.

D.2.1 Case Study

In this section we expand on the content included in **Section 5.2** to clarify the reader's understanding of the model by describing an example where we identify potential candidates that could fulfill the roles embedded in the model. Notably, as in the Facilitator Model case study, the example is meant to be illustrative of the relationships that may exist between the actors and the characteristics the actors should possess and does not signify that any organization mentioned has committed to participating in implementing the model. We focus on describing the actors that are unique to the Processing Center Model: the mini-grid developer and the PFI.

- **Mini-grid developer** serves the most important role under the Processing Center Model because in addition to providing reliable electricity service, it also owns the processing center, invests in the electric equipment, and is responsible for operating the equipment and repaying the equipment loan (alternative service delivery methods exist, see below). Mature companies with experience deploying appliance financing programs are better suited to implement the Processing Center Model. Examples of mature companies with a longer track record operating in Nigeria include GVE and A4&T, although additional examples may exist.
- **Private finance institution** (PFI) on-lends funding from the credit facility to the mini-grid developer. Like in the Facilitator Model, the PFI should have experience lending to the agriculture sector because it will have a better understanding of the prevalent risks, would have developed mechanisms to address these risks, and be more willing to lend for agricultural activities. Alternatively, banks that are already lending to mini-grid companies will be more comfortable extending credit for a new credit line. The following banks are lending or have demonstrated interest in lending to mini-grid developers in Nigeria: Sterling Bank, First City Monument Bank, Access Bank, WEMA Bank Debt.[lxxiv]

Alternative service delivery methods exist for the Processing Center Model that reduce the mini-grid developer's operational and risk burden. For example, the processing center can be owned by a third party, transferring both the operational burden and credit risk away from the mini-grid developer. Alternatively, the mini-grid developer could partner to transfer the operational burden. For instance, the mini-grid developer could partner with local small-scale processors under a profit-sharing initiative when the small-scale processor is unwilling or unable to replace their equipment with efficient electric equipment. The small-scale processor would operate the equipment, be responsible for the operational burden, and leverage their expertise in production. The mini-grid developer would be responsible for the credit risk, receiving the loan and owning the equipment. Under this arrangement, the Processing Center Model could also be used for Tier 1 activities without displacing local entrepreneurs.

D.2.2 Setting the Processing Center Model in Context

Like the Facilitator Model, similar approaches to the Processing Center Model have been proposed and tested before. For example, in the KeyMaker Model, the mini-grid company develops a second business line, using mini-grid electricity to produce and sell a product regionally or nationally. The mini-grid company partners with small-holder farmers to reliably off-take raw material, which it then processes and sells outside of the community. Economies of scope underlay the KeyMaker Model—the mini-grid company can compete with producers in peri-urban areas by leveraging its existing assets to develop the new business line and save on overhead costs. The KeyMaker model also reduces transport costs by processing products in rural communities and reducing the weight of the product.[188]

[lxxiv] Nigeria Power Sector Program, "NEP Shortlisted Financiers Database," 2019.

The design of the Processing Center Model and KeyMaker Model is similar, but we deepen and contextualize its application. The KeyMaker Model underscores the importance of accessing national and regional markets to ensure sufficient revenue and so the mini-grid developer owns the product and controls its supply. The Processing Center Model also captures scenarios where the small-holder farmers own and market the product and pay usage fees for using the equipment.

The KeyMaker Model has been tested before. For example, JUMEME in Tanzania runs its own fish freezing and delivery system to connect fishermen with local markets. Through this venture JUMEME identified a new business line which provides base load, improves capacity utilization, and provides an additional revenue stream.[189] Another variation of the Processing Center Model exists in Mokoloki, Nigeria. In Mokoloki's market, a third party owns a fee-for-service grinding business serving farmers that process their grain to sell as flour.

D.2.3 Roles and Responsibilities

The mini-grid developer carries out the most important role in this model and so the success of the model depends on selecting a high performing mini-grid developer with the technical and administrative capacity needed to develop expertise on and start a new business line. Alternatively, the mini-grid developer could partner with a local entrepreneur or other third party that contributes the expertise to operate the processing center and reduces the burden on the mini-grid developer. The PFI also plays an important role in vetting and selecting a suitable mini-grid developer to partner with. As such, the PFI should have the required expertise to evaluate mini-grid developers and ideally would have a track record of financing mini-grid developers. **Table 22** explains further.

Table 22: Roles and Responsibilities in the Processing Center Model.

Role	Responsibility	Characteristics
Mini-grid developer (Equipment purchaser and operator, and electricity provider)	• Purchase and maintain equipment that produces product to meet user preferences • Deliver sufficient access to well-functioning equipment • Ensure suitability of equipment with mini-grid system • Train equipment users on proper use of equipment • Apply for equipment loans and make loan repayments	Proven and reputable company with track record of operating reliably and administrative capacity to manage a new business line
PFI (Funder and loan provider)	• Assess and screen mini-grid developers and issue loans • Collect loan repayments	Financial institutions with expertise and experience evaluating mini-grid companies and lending to agriculture sector

D.2.4 Model Performance

Table 23 shows the Processing Center Model's performance against key criteria. As summarized, in **Section 5.2** the Processing Center Model meets most criteria with the exception of defining access to market and enabling inter-actor trust. It also scores better than the Facilitator Model for complexity and scalability. The Processing Center Model is suitable in communities where the mini-grid developer is the only investment-ready partner present—where small-scale processors are unwilling to upgrade their equipment— and for Tier 2 applications that are not prevalent in mini-grid communities.

Table 23: Processing Center Model Performance Relative to Key Criteria and Barriers to Implementation.

Performance criteria	Processing Center Model
Access to credit	✓
Access to market	✗
Awareness and education	✓
Incentives for reliable electricity access	✓
Inter-actor trust	✗
Burden on mini-grid developer	✓
Complexity	Low
Scalability	High

Access to market—like in the Facilitator Model, the Processing Center Model does not include an offtaker in its design and so the model performs poorly on this criterion. Nonetheless, users can reduce market and price risk in the model's application:

- Running pilots with ADPs and AMEFAN to test compatibility of equipment with user preferences before deploying at scale can reduce market risk by proving whether small-holder farmers like and are willing and able to pay to use the equipment.
- The recommended applications of the Processing Center Model conserve the quality of or pre-process crops, instead of processing crops into another product. As such, embedding this model within communities receiving inputs and training for cultivation also reduces market risk. Doing so would ensure that the mini-grid developer is working with small-holder farmers that have higher yields and so have higher demand for the equipment. It may also lead to higher revenue for the farmer from higher quality crops, increasing farmer margins and their ability to pay to use the equipment.

Awareness and education—users of the Processing Center Model can embed capacity building for mini-grid developers in the following areas:

- Running pilots with ADP and AMEFAN to test compatibility of equipment with mini-grids and ancillary equipment before deploying at scale and advising the mini-grid developer on equipment selection
- Partnering mini-grid developers with third parties that can operate the processing center can also address the need for capacity building in the new business line.

Although these services are not embedded in the design of the model, they are included in the design of the roadmap presented in **Section 6.**

Incentives for reliable electricity access—the design of the Processing Center Model motivates the mini-grid developer to provide high quality reliable service in order to attract customers and provide a large enough revenue stream to recover the equipment investment. Additionally, the design of the Processing Center Model motivates the mini-grid developer to select electric equipment to ensure compatibility with its electricity system and ensures that the mini-grid developer is involved in the equipment selection process from the start.

Interactor trust—the Processing Center Model performs poorly on interactor trust. The mini-grid developer is unlikely to have as deep and long-standing a relationship with agrarian communities as a cooperative or social lender that has been working in agrarian communities for years and has a track record offering extension services and other forms of support. As a result, compared to the Facilitator Model, it may be harder under the Processing Center Model to get buy-in from potential customers. There may be communities with a longstanding presence of a mini-grid developer but given the nascent stage of the mini-grid sector in Nigeria this scenario will more likely be an exception than the rule. An additional mistrust may arise if the mini-grid developer is displacing mobile processors serving various neighboring communities.

Burden on mini-grid developer—under the Processing Center Model the mini-grid developer is responsible for the operational burden and loan repayment and so, the model performs worse than the Facilitator Model for this criterion. However, alternative service delivery methods where the operational burden and credit risk are distributed to third parties would perform better.

Complexity—the Processing Center Model outperforms other models in its simplicity. The model does not require formal agreements to deploy and has the least number of actors to coordinate.

Scalability— Like the Facilitator Model, the Processing Center Model does not establish market linkages in its design. That is, the design of the model does not introduce a connection to an offtaker. As such, the Processing Center Model is suitable for activities and communities that already have access to a market to ensure the sale of the product. Additionally, the Processing Center Model requires fewer enabling conditions than the Facilitator Model as it only requires selecting a community with proven demand for the product. This means the Processing Center Model may have greater potential for widespread deployment.

D.3 *Offtaker-Based Model Overview*

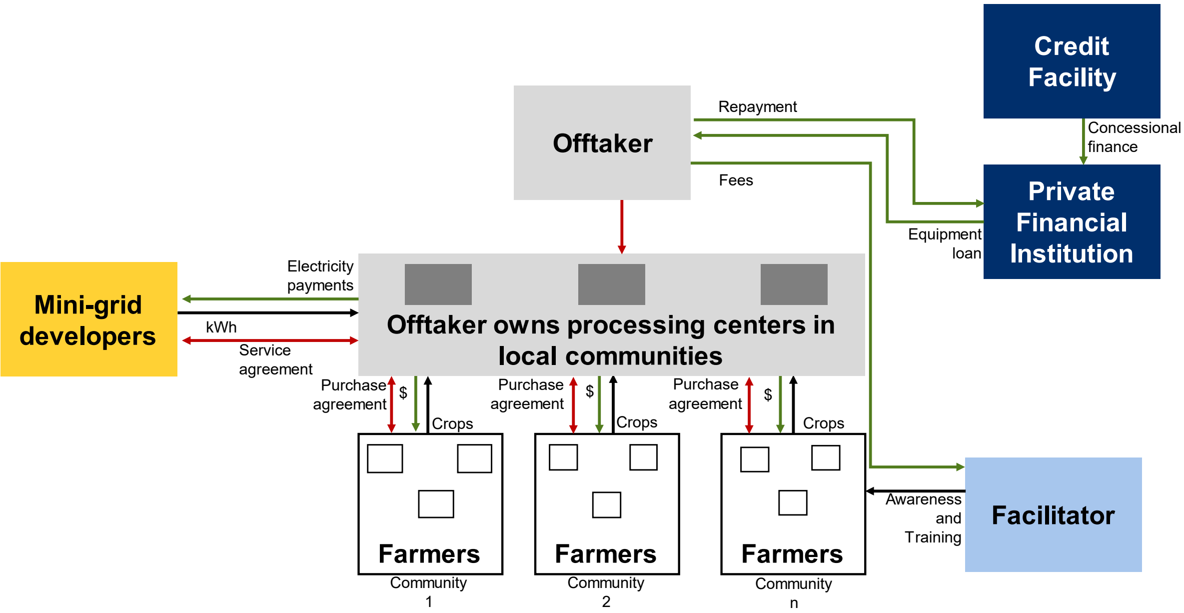
Offtaker-Based Models refer to a category of deployment models where a partnership with an offtaker to purchase and sell the product exists. Various service delivery methods exist depending on which actor carries out the operator role investing and owning the equipment. The operator role can be fulfilled by the offtaker, third party, farmer organization, mini-grid developer, or a joint venture that unites these actors to own and operate the equipment. However, the rest of this appendix focuses on the service delivery method where the offtaker invests and owns the equipment

The Offtaker-Based Model is suitable for activities that require volume to market and where a proven market does not yet exist. These activities bring a wider set of barriers that the design of the model must address. The Offtaker-Based Model embeds an offtaker with the market linkages to provide revenue certainty into the design of the model and de-risk the investment. The offtaker is a larger player compared to small-holder farmers and mini-grid developers and can coordinate across communities to meet larger volume requirements.

Figure 67 illustrates the institutional arrangements of the Offtaker-Based Model. Under the Offtaker-Based Model, the offtaker invests and owns the equipment.

The Offtaker-Based Model embeds actors with the required expertise to attract investment. The offtaker brings technical knowhow on production and the administrative capacity and business know-how to set up the processing center and manage its day to day operations. The offtaker also brings market access. The small-holder farmers ensure access to raw materials necessary for production. The facilitator connects farmers to the initiative, provides training, and supports local buy-in. The mini-grid developer brings in the expertise on energy systems to provide reliable electricity service.

Figure 67: Institutional Arrangements of the Offtaker-Based Model.



The Offtaker-Based Model develops a new business line that was not previously prevalent in local rural communities. This increases the demand for and revenue derived from their crops. For example, under a milk chilling application, dairy farmers increase their revenues from sales of milk that was previously lost because it could not be preserved. The offtaker has access to a certain supply of crops to meet the Nigerian market. The mini-grid developer has access to an anchor load. The local facilitator receives a new revenue stream from service fees.

The net benefit to the surrounding communities will depend on the specific application of the model. The surrounding community and families of farmers may gain access to electricity service at a lower price than would be available without a guaranteed energy offtaker. [lxxv] However, under the cassava chipping application, for example, the net impact to the surrounding community may be negative. Cassava chipping for ethanol production in export markets may drive up the price of local cassava and reduce the communities' ability to pay for a staple food. Further analysis of the wider societal costs and benefits of cassava chipping in rural communities is outside the scope of this study but should be assessed before deploying.

D.3.1 Setting the Offtaker-Based Model in context

Variations of the Offtaker-Based Model are being tested in Nigeria. Below we include an example of the Offtaker-Based Model deployed for milk chilling. The variations we observed do not establish a role for a mini-grid developer. Instead the offtaker invests in the energy system to power the processing center. These are small operations that solely power the processing center and where the required energy capacity to do so is small. An opportunity exists to expand these designs to develop a model that includes a mini-grid developer that also powers surrounding communities.

Arla Foods, a Danish dairy company partnered with the Kaduna State Government ('the Government'), Milcopal a local dairy cooperative, and local dairy farmers to develop the Milky Way Partnership. The Milk Way Partnership provides dairy farmers with access to grazing land and collects and chills milk to support the local dairy industry. Under the Milk Way Partnership, the Government provided access to grazing land and infrastructure services of water and electricity. Arla invested in milk processing center to collect and chill milk harvested and purchased from farmers. Arla uses the milk to develop dairy products for the Nigerian dairy market, a quickly growing market. Milcopal provides awareness and education to attract farmers to the scheme and train them to increase their yields.

The partnership provides benefits to all partners. Dairy farmers have access to permanent grazing land and water improving the health of their herds and increased revenue from milk sales from milk that was previously lost because it could not be chilled. Arla Foods has access to a local source of dairy, reducing its import bill. And the Government supports the development of a local industry, that reduces imports and improves the livelihoods of its small-holder farmers.[lxxvi]

Arla Foods is expanding on this concept to develop the Damau initiative. The Damau initiative develops communities for herder families that will include milk processing centers. It is larger than Milky Way Partnership and will require a larger energy supply. The Damau initiative may provide a unique opportunity to partner with mini-grid developers to power these communities.

[lxxv] Additional study is needed to verify the impact to the mini-grid system of the applications considered for the Offtaker-Based Model. The analysis to assess the impact of processing load on mini-grid financial performance was only conducted for Tier 1 activities which are not recommended for the Offtaker-Based Model.

[lxxvi] https://www.arla.com/sustainability/sustainable-dairy-development/

D.3.2 Roles and responsibilities

Under the Offtaker-Based Model, the offtaker carries out the most important and demanding role. The offtaker invests and operates the equipment and carries the credit risk and operational burden.[lxxvii] Fulfilling the operator role of the model with an organization that is not locally based means that additional partnerships are needed. Partnerships with a facilitator can provide linkages to small-holder farmers. **Table 24** explains further.

Table 24: Roles and Responsibilities in the Offtaker-Based Model.

Role	Responsibility	Characteristics
Offtaker (Equipment investor)	• Offtake inputs from small-holder farmers • Advise facilitator on the specifications for raw material and quality standards • Carry out pre-processing or processing • Select, load, and transport pre-processed or processed product to hub for further processing or transport to market • Market product	• Access to national or international markets to sell product • Enough purchasing power to reliably off-take crop from small-holder farmers • Administrative capacity to oversee program implementation • Technical expertise to carry out production • Strong reputation to inspire confidence that revenue stream is certain
Small-holder farmers (Input Provider)	• Supply crop and meet terms of purchase agreement • Participate on training	• Recipient of extension services to improve yields and quality of crop
Facilitator (Awareness and Training)	• Serve as a gateway connecting the offtaker to the farmers • Carry out awareness campaigns in local communities to attract farmers and ensure buy-in • Support farmers and offtakers in negotiating purchase agreements • Provide training on quality and increasing yields	• Embedded in and possessing deep knowledge of farmer communities to identify reliable and capable small-holder farmers to work with • Technical expertise to provide training on yield and quality improvement
Private Financial Institution (Loan provider)	• Carry out credit risk assessments (for offtaker) and issue loans	• Experience lending to agriculture initiatives with experience and expertise to assess agriculture risks
Mini-grid developer (Energy provider)	• Deliver reliable and sufficient power at agreed upon times and tariff • Advise on equipment specification to ensure suitability of equipment with mini-grid system	• Proven and reputable company with ability to offer reliable and sufficient power at agreed upon tariff

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[lxxvii] Although variations on the service delivery method would distribute these responsibilities differently.

D.3.3 Model performance

Table 25 shows how the Offtaker-Based Model performs against key criteria. The Offtaker-Based Model meets the most performance criteria compared to all of the models considered. However, it is able to meet the key criteria by ramping up complexity and reducing its scalability. The Offtaker-Based Model is the most complex and least scalable model considered.

Table 25: Offtaker-Based Model performance Relative to Criteria and Barriers to Implementation.

Performance Criteria	Performance
Access to credit	✓
Access to market	✓
Awareness and education	✓
Incentives for reliable electricity access	✓
Inter-actor trust	✓
Burden on mini-grid developer	✓
Complexity	High
Scalability	Low

Access to credit—the credit recipient under the Offtaker-Based Model is an established offtaker. The offtaker will have a credit history and will be more able raise financing compared to the small-holder processors or mini-grid developer. Nonetheless, the initiative will cover a business line or process that has not been proven. Partnering with a reputable offtaker with access to a large proven market to sell product reduces the uncertainty over the revenue stream and credit risk. The partial credit guarantee on the equipment loan also reduces the credit risk for the PFI.

Access to market—the Offtaker-Based Model embeds market linkages in its design by including the offtaker. Partnering with reputable offtakers with access to large markets to sell the product and selling a product with significant market demand reduces this risk. For example, Arla produces various dairy products that it distributes nationally. Arla is able to reduce market and price risk by diversifying the product categories it offers and distributing to a large market with growing demand for dairy products.

Awareness and education—the Offtaker-Based Model includes a facilitator to provide awareness and education needs. Establishing a partnership with a facilitator can reduce risk of not accessing sufficient crop to produce enough to recover the equipment investment. Partnering with reputable cooperatives and/or extension agents with track record of increasing yields and producing high quality product to fulfill the facilitator role also reduces this risk. Obtaining farmer buy-in by ensuring that participating in this initiative aligns with farmer priorities is also important. Partnering with a facilitator that is tightly embedded in local communities and that farmers trust is important. Depending on the skills that local organizations have, the role of building awareness and connecting small-holder farmers to the initiative may be separated from capacity building and providing extension services.

Incentives for reliable electricity access—like the Facilitator Model, the Offtaker-Based Model includes a service agreement to align expectations in this case between the mini-grid developer and offtaker. Similar to the Facilitator Model, the mini-grid developer should be brought on early to advise on equipment selection and ensure suitable pairing of equipment with the mini-grid system.

Interactor trust—the Offtaker-Based Model includes the facilitator to connect the offtaker to small-holder farmers and build buy-in in the local community. The facilitator needs to be a trusted organization embedded in local communities with established relationships with small-holder farmers.

Burden on the mini-grid developer—the Offtaker-Based Model does not impose additional operational burdens and risks beyond those of providing reliable electricity service.

Complexity—the Offtaker-Based Model is the most complex model considered. It brings together the largest number of partners and requires the most agreements to align and clarify expectations and responsibilities across these actors.

Scalability—the Offtaker-Based Model requires the greatest number of conditions to deploy, limiting its scalability. It requires organizations to fulfill the facilitator role that are embedded in local communities to gain farmer buy-in and technical skills to provide training to improve farmer productivity. Most importantly, it requires an offtaker willing to take on a central operator role and invest in equipment in rural communities.

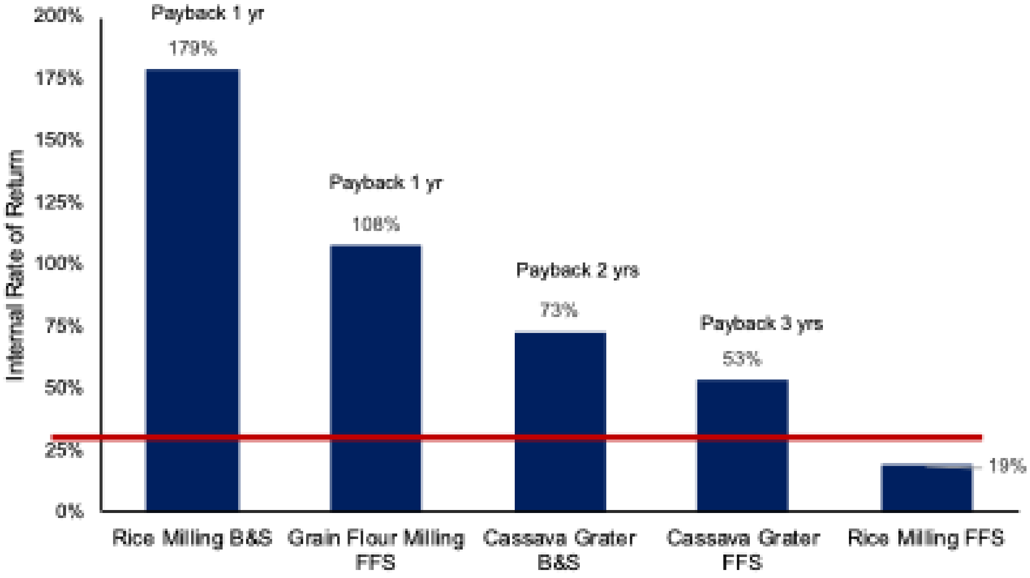
APPENDIX E DEPLOYMENT STRATEGY AND FINANCIAL IMPLICATIONS

This appendix provides a more in-depth description of the financial implications for Tier 1 activities and should be read together with **Section 6** to fully understand the deployment strategy to fund equipment purchases. Whereas **Section 6** focuses on the results and recommendations, this appendix also provides additional detail and describes the approach and assumptions used. Specifically, this appendix provides a more detailed description of the financial instruments needed to unlock commercial financing and fund electric equipment purchases. These financial instruments are consistent with those defined in the previous sections, but we explore them in further detail here. We then restate the estimated size of investment needed nationally to fund equipment purchases for Tier 1 activities but provide additional detail on the assumptions and approach used in the analysis.

E.1 *Unlocking Commercial Finance and Funding Equipment Purchases*

Figure 68 shows the internal rates of return and expected paybacks of the equipment purchases for Tier 1 activities. The expected return on investment for most electric equipment purchases considered are large enough for small-scale processors to afford a cost of capital of around 30 percent.[lxxviii] One notable exception is rice millers operating under a fee-for-service sales modality (FFS rice millers). FFS rice millers would be unable to afford a 30 percent cost of capital. Different financial instruments should be considered for situations where the small-scale processor is profitable enough to cover higher rates of commercial sources of funding, and for those where the processor cannot immediately attract commercial financing.

Figure 68: Summary of Financial Results of Tier 1 activities;



Red line indicates a 30% cost of capital for reference

[lxxviii] Interview with local commercial bank in November 2019. This interest rate is on the high end and other financial organizations, particularly development financing institutions charge lower interest rates. For example, the Bank of Industry charges around 10 to 15 percent interest rates for loans to mini-grid developers and loans of up to 5 percent to micro-processors under their GEEP program.

For small-scale processors purchasing equipment for activities that can recover the market cost of capital, the need is for financial instruments to de-risk investment. This can enable private finance institutions (PFIs) to lend for a longer duration than the 12-month tenor of loans provided today for activities connected to the small-holder agricultural sector. [lxxix] On the other hand, small-scale processors purchasing equipment for activities that cannot currently recover the market cost of capital will also need concessionary funding to reduce the blended cost of capital to affordable levels until perceived risks fall and market rate debt becomes affordable. **Figure 68** illustrates that an affordable blended cost of capital for FFS rice milling is under 19%.[lxxx] This means that the cost of capital provided by existing concessionary funding programs offered to micro and small processors in Nigeria is affordable for FFS rice milling—Bank of Industry offers loans for small-scale processors with an interest rate under five percent.[lxxxi] While not an immediate change, it is reasonable to expect commercial financiers to begin offering reduced interest rates to small-scale processors once sufficient scale and payment history has been demonstrated.

Several financial instruments can be considered to de-risk investment and crowd-in commercial financing:

Senior and subordinated debt. Credit lines designated to on-lend to small-scale processors can encourage lending by PFIs. For it to be affordable, the credit lines should provide debt with longer duration than the 12-month duration offered to micro, small, and medium enterprises in Nigeria. Our analysis shows that the payback of the electric equipment considered under Tier 1 range from under one to three years and so loan tenors of credit lines will need to be longer to allow PFIs to on-lend to small-scale processors.

Partial credit guarantees. PFIs in Nigeria lend a low share of their loan portfolios to agriculture, particularly to finance upstream activities near cultivation. PFIs without experience lending to the agriculture sector lack the expertise to assess risks and manage agricultural loan portfolios. However, several PFIs do lend to the agriculture sector today (see **Section 6.3**), and could be supported to lend to small-scale processors with the addition of partial credit guarantees to de-risk the investments.

A partial credit guarantee is a legal agreement stipulating that the guarantor would reimburse the debtholder in the event that the borrower cannot fulfill the unpaid principal amount of the loan.[l] Depending on the terms of the guarantee, the investor may recover all or a partial amount of the loan's unpaid principal. The size of the guarantee can vary. A study by the Global Impact Investing Network analyzing 44 guarantees in the impact investing space, guarantee sizes tend to aggregate around the ends of the spectrum, with 19 offering 25 percent or less coverage and 19 offering 75 percent or greater coverage. Coverage ratios for loans to small-holder farmers or related businesses are on the higher end of the spectrum.[190] For instance, the Central Bank of Nigeria through its Agricultural Credit Guarantee Scheme Fund (ACGSF) and NIRSAL offer coverage ratios of up to 75 percent for guarantees for small-holder farmers.[lxxxii]

Life Insurance. As opposed to the credit guarantee which covers loan repayment in the event of a loan default, life insurance would cover the loan repayment in the event of the small-scale processor's death. Life insurance reduces the riskiness of the investment by protecting against the death of the small-scale processor. The small-scale processor would be the policy holder and in the event of the small-scale processor's death the insurance company would pay the remaining portion of the equipment loan and in so doing remove the repayment burden from the small-scale processor's family and protect the PFI from loan default and reduce its debt collection cost.

[lxxix] LAPO Microfinance Ltd. has one of the largest agriculture loan portfolios for small-holder famers and offers loan tenors of one to 12 months. See website: https://www.lapo-nigeria.org/loans/agricloan

[lxxx] These internal rates of return are based on the economic viability analysis presented in **Section 4**.

[lxxxi] Interview with representative of Bank of Industry's GEEP Program. Bank of Industry charges higher interest rates (10 to 15 percent) for loans in other sectors.

[lxxxii] NIRSAL website: https://nirsal.com/products-and-services/;

Grants for funding initial set-up costs and capital cost reduction. Initial coordination, preparation, and studies are needed to connect actors through workshops, fund pilots to test, identify, and standardize suitable equipment to connect to mini-grids, and conduct monitoring and evaluation to demonstrate the success of and lessons learned from pilots and programs. Grants are suitable for financing set-up costs and pre-investment studies because these investments do not offer an immediate and direct financial return to the investor, but they are critical to attract commercial financing later on. Additionally, matching grants could be used to reduce the blended cost of capital for small-scale processors that are unable to afford the market rates of capital local banks provide.

Grant funding could also be used to fund rebates to encourage small-scale processors to acquire loans and PFIs to on-lend to facilitators serving small-scale processors. For example, performance-based rebates for small-scale processors could reduce the cost of capital and reward repayment by paying rebates to small-scale processors that meet a certain number of payments. Similarly, performance-based rebates could reward PFIs that provide a defined percentage of their portfolios to loans to facilitators. Rebates could be used if the uptake and provision of financing is lower than expected during the implementation phase.

E.2 *Estimated Funding Required*

To jump start the electrification of productive use alongside mini-grids for priority activities will require substantial investment, but the total amount is within the capabilities of existing funding programs.

Table 26: Indicative Investment Required for Tier 1 Activities

	Number of processors per community	Equipment capex per processor ($)	Number of mini-grid sites by 2023	Total Investment Size ($)
Cassava grater	3	1,100	1,300	4,290,000
Rice mill	5	1,800	1,300	11,700,000
Grain flour mill	4	850	1,300	4,420,000
Total equipment investment				20,410,000
Pre-investment costs				2,000,000
Insurance, fees and operational expenses (25% of equipment investment)				5,102,500
Total funding required				**27,512,500**

To develop this estimate, we considered the aggregate cost of electric equipment needed within planned or operational mini-grid projects in Nigeria (see **Table 26).** The Nigeria Electrification Project (NEP) aims to develop approximately 1,200 mini-grid projects, and we estimate there are close to 100 existing sites in Nigeria (see assumptions in **Appendix E.3**). Coupled with our field survey, which identified the number of existing small-scale processors in each community, and estimated equipment costs, we estimated the investment required for equipment purchases to support Tier 1 activities. Pre-investment costs are estimated based on a yearlong pilot deploying and testing the performance of equipment in three communities, and a multi-year pilot testing the performance of the business models (additional information on assumptions is included in in **Appendix E.3**).

These calculations assume that current markets in these communities can only sustain the existing number of processors. This approach may underestimate the number of processors a community can sustain because we are not considering would-be processors that currently do not have equipment due to lack of access to credit at reasonable terms, and we are not estimating the longer-term potential for community growth as a result of electrification. However, we believe conservative estimates of product demand are warranted because the Facilitator Model does not explicitly embed mechanisms to create product demand, and so growth cannot be guaranteed. Additionally, the potential number of small-scale processors in each community will be limited by the total volume of crops that processors have access to, which could also limit growth potential (see break-even volume analysis include in the case studies assessed in **Appendix C**). It is also possible that as the number of electrified processors grows it is likely that the support mechanisms identified here will be less important, as this type of investment becomes commonplace.

We estimate the insurance, fees, and operational expenses to be around 25 percent of the investment required (see **Appendix E.3**).

The operational expenses cover the costs of administering and disbursing funds by the credit and grant facilities. We assume that the operational expenses of PFIs are included in the debt rates they charge because the operational expenses of administering loans are part of a PFI's normal operations.

We also assume that small-scale processors will lack funding to contribute to a borrower's deposit, and therefore the total funding required from commercial debt and grant sources is equal to the total funding required. We estimate that around **$13,200,000** of the total funding will be sourced with grant funding and the remaining **$14,300,000** will be financed with commercial debt. To calculate the breakdown of grant to debt funding we assume the following components are funded with grant funding: the proportion of the FFS rice mill investment and corresponding fees and OPEX needed to achieve an affordable blended cost of capital (assumed as 3.75%)[lxxxiii] for FFS rice milling plus pre-investment costs. The remaining required investment is funded with commercial debt.

This discussion has focused on funding required to deploy Tier 1 activities, in order to focus attention on quick-win opportunities. Investing in these areas will deliver impact in the short- to medium-term and will help guide future efforts for financing electric equipment purchases in other applications. However, as discussed in **Section 3**, Tier 2 activities hold significant potential but will require additional barriers to be overcome before they are commercially viable and ready to implement. Additional funding is required to support these activities and scale agricultural productive use electrification across a larger set of uses in Nigeria.

E.3 *Assumptions for Financial Implications*

The estimated funding requirement presented in **Section 6.2** and above includes three cost components: **equipment costs, pre-investment costs, and fees and operational expenses**. Assumptions used to calculate each component are included below.

E.3.1 Assumptions to calculate equipment costs

Number of processors per community

	Unit	*Value*	*Description*
Cassava grater	Number	3	Average number of processors in survey
Rice mill	Number	5	Average number of processors in survey
Grain flour mill	Number	4	Average number of processors in survey

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[lxxxiii] This is the average interest rate charged by the Bank of Industry in its Government Enterprise and Empowerment Programme (GEEP), a program targeted towards providing access to credit to micro and small processors and traders and small holder farmers.

Equipment cost

Cassava grater	$	1100	Cost provided by local vendor
Rice mill	$	1800	Cost provided by local vendor
Grain flour mill	$	850	Cost provided by local vendor
Number of mini-grid sites by 2023	Number	1300	NEP aims for 1,200 mini-grid projects, and we estimate around 100 existing sites in Nigeria[lxxxiv]

E.3.2 *Assumptions to calculate pre-investment costs*

Pre-investment costs include the costs for: **equipment pilots, business model pilots, dissemination and coordination activities, and an independent verification agency**. Assumptions for each component are included below.

Equipment pilot

	Unit	*Value*	*Description*
Total number of cassava graters	Number	12	Assuming 2 communities for each of the 3 major agro-ecological zones (total 6 communities) and 2 processors per community
Total number of rice mills	Number	12	
Total number of flour mills	Number	12	

Equipment Cost

Smart Meter cost	$	106	RMI research
Equipment transport (percentage of equipment cost)	%	20%	Estimate
Deployment cost (percentage of equipment cost)	%	20%	Estimate

Community selection and data collection

Total Field Team	Number	12	Team of 2 for each community
Field Team Labor cost	$/day	265	Estimate of labor and ground transportation
Field Team No of days per month	Number	8	Assuming 2 days per week
Length of pilot	Months	12	Assuming yearlong pilot

[lxxxiv] REA, "Nigeria Investment Brief", December 2017 includes a target of 1200 new sites for NEP. The World Bank's Project Appraisal Document for the Nigeria Electrification Project (PAD2524) includes 83 projects as of 2018 in the country (pg. 67).

Business model pilot

	Unit	*Value*	*Description*
Data analysis, oversight, monitoring and evaluation team	$	800,000	Estimate
Facilitator Fees (percentage of equipment cost)	%	5%	Fees for extension services (stakeholder interviews February 2020)

Equipment Quantity

Total cassava graters	Number	12	Assuming 2 communities for each of the 3 major agro-ecological zones(total 6 communities) and 2 processors per community
Total rice mills	Number	12	
Total flour mills	Number	12	

Dissemination and coordination

	Unit	*Value*	*Description*
Cost of dissemination workshop	$	40,000	Estimate
Estimated no. of workshops	Number	8	Assuming two workshops for each step in roadmap

Breakdown of grant to private debt

	Unit	*Value*	*Description*
Target blended cost of capital for FFS Rice Milling	%	3.75%	Average of low and high interest rate cost under BOI's GEEP
Grant	N/A	• Assuming that all pre-investment costs are funded through grant • Assuming that around 90% of equipment, fees, and operational expenses (OPEX) for FFS rice milling are funded through grant	
Private debt	N/A	• Assuming that all cassava milling and rice milling equipment purchases, fees, and OPEX are financed through private debt • Assuming that around 10% of equipment, fees, and OPEX for FFS rice milling are financed through private debt	

Independent Verification Agency

	Unit	*Value*	*Description*
Independent verification agency (main program) annual cost	$	75,000	Estimate
Number of Years for Audits	Years	5	Average duration of a World Bank funded program, assuming 1 annual audit

E.3.3 Assumptions to calculate breakdown of funding and fees and operational expenses

Fees and OPEX (% of equipment purchase, one time)	*Unit Value*		*Description*
Credit guarantee fee (Percentage of equipment loan)	%	4%	Stakeholder interviews in February and March 2020
Facilitator fee (Percentage of equipment loan)	%	4%	
Operational expenses (Percentage of equipment loan)	%	12%	World Bank budgeted 10% in OPEX for component 2 of its National Electrification Project (NEP),pg. 110 PAD2524
Insurance fee (Percentage of equipment loan)	%	5%	Stakeholder interviews in February and March 2020
Total fees and OPEX	%	**25%**	

APPENDIX F MAP OF KEY STAKEHOLDERS

This section presents interest groups, community organizations, development partners, government, and financial institutions who may support deployment of productive use interventions. This analysis was not comprehensive to remain streamlined and was the first step in identifying specific roles for stakeholders supporting the deployment strategy included in Section 6. The stakeholders are organized by the role they could potentially fulfill in the business models.

Role: Assess, test, and certify equipment and supply equipment

Equipment research institutes

National Research Institutes: There are 18 National Agricultural Research Institutes under the Federal Ministry of Agriculture and Rural Development ('FMARD'). A subset of these are included below:

National Center for Agricultural Mechanization ('NCAM') has evaluated performance of agricultural equipment, developed prototypes, developed standards for equipment, and disseminated proven technologies among potential suppliers or investors. They have comprehensive work ranging from equipment testing and development and disseminating proven technologies for many technologies including cassava graters and peelers. They have found proven technologies for: multi-purpose mills, garri fryers, cassava graters, cassava mash press, maize thresher, batch dryer.[lxxxv]

Institute for Agricultural Research ('IAR') has an agricultural mechanization research program that focuses on developing and evaluating production and post-harvest technologies. Specifically, IAR works with vendors and evaluates and certifies locally manufactured and imported equipment to determine suitability and quality. It also designs and develops equipment that meets needs of Nigerian farmers including small holder farmers in Nigeria. Some of their developments include prototypes for: a maize dehusker, millet and soybean thresher, sorghum thresher.[lxxxvi]

National Agricultural Extension and Research Liaison Services ('NAERLS') develops and supports transfer of agricultural innovations. Includes two departments that may be relevant for the design of a deployment strategy:

- The agricultural engineering and irrigation department which verifies and develops equipment and provides training. Equipment covered includes threshers, dryers, and crop processing machines
- The Agric Media Department develops media to end users that could be leveraged for outreach activities.[lxxxvii]

Other research institutes:[lxxxviii]

- Cocoa Research Institute of Nigeria (CRIN);
- Institute for Agricultural Research & Training (IAR&T);
- Lake Chad Research Institute
- National Animal Production Research Institute (NAPRI);
- National Cereal Research Institute (NCRI);
- Nat. Inst. for Fresh-Water Fisheries Research (NFFR);
- National Horticultural Research Institute (NIHORT);
- National Root Crops Research Institute (NRCRI);

[lxxxv] NCAM website: https://www.ncamng.org/achievements/

[lxxxvi] IAR website: https://iar.abu.edu.ng/pages/agrmechrech.html

[lxxxvii] NAERLS website: https://naerls.gov.ng/

[lxxxviii] CORAF website: http://www.coraf.org/nigeria/

- National Veterinary Research Institute (NVRI);
- Nigerian Institute for Oil-Palm Research;
- Nigerian Stored Products Research Institute (NSPRI);
- Nig. Institute for Oceanography & Marine Research (NIOMR);
- Rubber Research Institute of Nigeria (RRIN).
- Agricultural Research Council of Nigeria (ARCN)
- CORAF
- CARD Coalition for African Rice Development[lxxxix]
- International Livestock Research Institute[xc]

Equipment vendors

Agricultural Machineries and Equipment Fabricators Association of Nigeria (AMEFAN) develop and sell equipment to support agriculture. AMEFAN aims to promote the production of equipment to agreed standards and specifications by members and coordinate activities and support members to improve locally available technologies. They have an accreditation process where they screen manufacturers by screening their workshops and assess their supply chain for spare parts. They have a comprehensive databank of members and members include manufacturers of processing equipment for roots and tubers, cereals and grains, and oil seeds and nuts.[xci]

Selection of manufacturers (fabricators) and equipment importers

The following is a sample of manufacturers and importers based in Nigeria. The vendors generally provide a one-year warranty for the equipment for Tier 1 activities. Additional information included in **Appendix B**.

- Bennie Agro Machine fabrication Limited
- UNIC & Sons LTD
- Chinige Technology services LTD
- NOVA Technologies
- Process concepts and technologies limited
- Doing
- Nnayang Goodway
- Weilai Machinery
- Macro
- Hanigha Nigeria Limited

Role: Provide funding and technical capacity building

Federal Ministry of Agriculture and Rural Development—main policy-making agency in agricultural sector to support food security, stimulate employment, promote production of raw materials and access to markets. Flagship programs include the National FADAMA Project which closed in December 2019 and provided farmers financing to support access to inputs and machinery and extension services to improve yields. The APPEALS program works with same farmer groups created under the FADAMA project, but with a focus on six states with a stronger commercial focus.

State Government Offices through the Ministries of Agriculture provide training and extension services to farmers

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[lxxxix] Not a national research institute

[xc] Not a national research institute

[xci] AMEFAN website: http://amefan.org/about-us/

State Agricultural Development Projects ('ADP') implement state-driven agricultural support projects. For example, they work with NCAM to provide linkages between farmers and national research institutes.

World Bank—development finance agency providing funding to FMARD's flagship programs including FADAMA and APPEALS. The World Bank has planned disbursements of $200 million over the next five years with the APPEALS program.[xcii]

African Development Bank— development finance agency providing funding to support the Agro-Processing Zone project that aims to aggregate raw material and develop processing zones in 14 sites that will serve as ecosystems with the necessary infrastructure needed to process raw materials and capture additional value in agriculture value chains.

KfW in collaboration with other development finance institutions (CDC Investment works—Impact Fund, AfDB, Dutch Good Growth Fund, Federal Govt of Nigeria) developed the Fund for Agricultural Finance in Nigeria (FAFIN) which offers long term finance and technical assistance to agriculture SMEs in Nigeria. FAFIN does not target small-holder farmers but SMEs that have at least US$1Mn in revenue.

Central Bank of Nigeria provides incentives for the banking sector to invest in agriculture sector. It has various interventions including providing subsidized loans to lower the effective interest rates and guarantees to back commercial loans to the sector.

Nigeria Incentive-Based Risk Sharing System for Agricultural Lending ('NIRSAL') credit facility aiming to de-risk agricultural lending by providing guarantees for farmer investments through cooperatives. Provide guarantees in the Anchor Borrower's Programme. The Anchor Borrower's Programme was developed by Central Bank of Nigeria and provides financing, extension services, and market linkages to farmers. Within this programme, NIRSAL backstops loans to farmers, local banks collect payment from offtakers, deduct loan charges, and the remaining balance is deposited in farmer accounts.

USAID Feed the Future (and partners, like Konexa, Chemonics, etc) provides extension services to smallholder farmers and SMEs and access to finance and better agricultural inputs and technologies.

AGRA provides two levels of intervention: 1) support to federal and state level agencies in design and implementation of policies to support agribusiness and 2) farmer support via training to improve yields and quality and derisking of investments in the agriculture sector including investing in public private partnerships and new technologies and systems and de-risking loans to small holder farmers and other value chain actors.

GIZ provides training to small holder farmers on agricultural practices and business skills and support them in accessing credit by linking them to micro-finance partners that provide soft loans (active in rice and cocoa).

Sasakawa not for profit providing capacity building to farmers to improve agricultural practices and support technology transfer. Work through a network of trained coordinators and extension agents which in turn train farmers. Active in Kaduna and Cross River. All states include Adamawa, Bauchi, Gombe, Jigawa, Kano, Kaduna, and Zamfara, Anambra, Benue, Cross Rivers, Gombe, Katsina and Ogun States.[xciii]

Bill and Melinda Gates Foundation provide training and support to improve access to inputs (tools, seeds, systems) to increase the yield of crops (yams, cassava, sorghum, cowpeas, rice) and productivity of livestock.

[xcii] World Bank website: https://projects.worldbank.org/en/projects-operations/project-detail/P148616?lang=en#finances

[xciii] Organization's website: https://www.saa-safe.org/www/nigeria.html

Techno-Serve international not for profit, in Nigeria work focuses on increasing smallholder farmer productivity and income by improving access to inputs and finance and strengthening market linkages.

Proximate Agro Solution provide farmers with mobile and digital platforms to provide ground level support to link farmers with inputs (tractors), finance, extension services, and access to markets.

CNFA Cultivating New Frontiers in Agric international not for profit that designs agricultural development and entrepreneurship initiatives. Partnered with Feed the Future for the Agribusiness Investment Activity project running from 2018 to 2023 which aims to improve the regulatory and policy framework to improve ease of doing business, training farmers in production and processing processes, and providing finance. Also working with Feed the Future and Nestle to improve the quality of maize and soybean that Nestle sources from local farmers (2017 to 2020). The program trains small holder farmers, intermediaries, and retailers to improve practices in Kaduna. It also maps the producer association and cooperatives that support farmers in improving yield and product quality of maize and soybean.[xciv]

IDH the sustainable trade initiative Cassava initiative provides technical assistance to integrate small holder farmers into cassava processor supply chains. They provide support at both ends of the value chain, providing input support to improve yields and support for mechanization services, as well as connections to processors and end-buyers. They implemented a scheduled and agreed supply scheme between the processor and farmers and aim to establish processors within 50km radius from farms. They aim to improve livelihoods by improving productivity, reducing yield loss, and securing markets. https://www.idhsustainabletrade.com/sectors/cassava/

Bank of Industry (BOI) development finance institution that provides financing to micro, small and medium, and large enterprises to support the expansion, diversification, and modernization of the Nigerian economy. BOI intervenes across various sectors and scale of enterprises. In the micro enterprise segment, the focus is to support the supply of input for industries. Agriculture focused financial products connect manufacturers to farming clusters and fund farming inputs. Government Enterprise and Empowerment Program (GEEP) provides loans with accessible interest rates and less stringent requirements for creditworthiness to associations or clusters of market traders and small-scale farmers.

Sterling Bank provides financing to the agri-business sector. They also work with DFIs investing in agri-business including AfDB, Bank of Industry, Central Bank of Nigeria (Anchor Borrower's Programme).

Crowd funding digital platforms tap into investments from wealthier individuals from urban areas or the diaspora to fund small holder farmers. Platforms provide financing, access to inputs (seeds, fertilizer), training, and markets for sale of their products. Examples of indigenous crowd funding sites include: FarmCrowdy, ThriveAgric, Farmkart, PorkMoney, E-Farms Nigeria https://invoice.ng/blog/crowdfarming-agricultural-startups-nigeria/

Development Bank of Nigeria aims to increase access to finance for SMEs (not solely focused on agriculture SMEs). Provides wholesale funding and risk sharing facilities to financial institutions that on-lend to MSMEs. Tenors of up to 10 year and use market rates. DBN also provides partial credit risk guarantees and capacity building to the financial institutions and ultimate end borrowers. https://www.devbankng.com/pfi

Babban Gona offers support to farmers including inputs, training, financing and access to markets and storage. Present in Kaduna and Kano and work with maize, rice, and soybean. Organize small holder farmers into cooperatives.

One Acre Fund offers support to farmers including training, inputs, credit, storage, and insurance. Farmers need to repay loans by harvest time. Only work in Niger state and only support maize.

[xciv] Organization's website: https://www.cnfa.org/programs/?filter_region=africa&filter_country=ng&filter_expertise=all&filter_status=all

Farmer (Community) Organizations

Various farmer-led organizations exist in Nigeria. A selection of these are listed below:

- All Farmers Association of Nigeria
- Young Farmers Association of Nigeria
- Fadama Community Associations (FCAs) and Fadama User Groups (FUGs) established under FADAMA
- Rice Farmers Association of Nigeria
- Catfish Farmers association

<u>Role: Offtakers</u>

A non-exhaustive selection of offtakers is included below:

- Arla
- Ayoola Foods
- Dangote
- Diageo
- FMN Flour Mills Nigeria and Wacot
- Matna Foods
- Nestle-remote
- Olam
- Saj Foods Kaduna
- TGI

<u>Role: Supply electricity</u>

A non-exhaustive list of mini-grid developers in Nigeria is included below:

- Arnergy
- ACOB
- Havenhill Synergy
- EmOne
- Go Solar
- NayoTech
- GVE
- PowerGen
- Rensource
- Rubitec Solar
- Waste 2 Watt
- FMP/REA
- A4&T Power Systems
- CESEL
- Ondo State Electricity Improvement and Access Scheme
- REA
- Prado Power
- Power Gen

Other

- AFEX—multi-service first focused in the agriculture sector in Nigeria. They run extension programs and offtake commodities for trading and operate a digital platform for trading between producers and buyers, among other initiatives. More information here: https://afexnigeria.com/
- SABEX, the world's first end-to-end blockchain commodities trading and financing platform
- Binkabi—digital commodity network for trading. Binkabi streamlines commodity trading process and allows banks to lend against warehouse receipts and contracts.[xcv]

[xcv] Company website: https://www.binkabi.io/about

APPENDIX G LITERATURE BIBLIOGRAPHY

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APPENDIX H FULL VERSION OF SURVEY

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