Ayuda en Acción

Market Analysis

Solar Cooling and Drying Potential for Agriculture and Aquaculture Value Chains in Northern Uganda

Acknowledgement page

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Table of acronyms

Acronym	Description
AeA	Ayuda en Acción
CREEC	Centre for Research in Energy and Energy Conservation
DFI	Development Finance Institute
DRE	Distributed Renewable Energy
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MEMD	Ministry of Energy and Mineral Development
kWh	Kilo Watt hours
MW	Mega Watts
kV	Kilo Volt
PURE	Productive Use of Renewable Energy
GDP	Gross Domestic Product

Executive Summary

The limited access to electricity in Uganda presents significant opportunities for adoption of distributed renewable energy (DRE), which will bring about economic empowerment through widely increased incomes, and ultimately improve community resilience.

Already, off-grid energy solutions comprise 35% of the country's energy access rate of 54% compared to only 19% provided through the grid. In Northern Uganda, the total energy access rate is a mere 12%[3,17].

A particularly promising pathway is through applying productive uses of renewable energy (PURE) to agriculture: a significant sector that employs over 70% of the working population and contributes over 23% of the national Gross Domestic Product (GDP)[3].

Solar-powered technologies such as dryers and cold storage units will deliver tangible benefits across the value chains, increasing incomes for both smallholder farmers and agribusinesses such as traders[3,5,11].

The market size of West-Nile is estimated at $216 million with 45% of that ($97 million) spent on food and beverages. Priority crops are cassava, maize, sesame, tomatoes, and fish. Cassava is prime for solar drying as it is highly perishable if not preserved after 48 hours, and the dried product is sold for 50% more than the fresh product[5].

This study serves as a valuable guide when developing pilots and/or commercial projects that are aimed at enhancing post-harvest management practices in the region through PURE projects. It combines wider context analysis with key market insights into post-harvest management practices in Northern Uganda, specifically focusing on Lamwo, Obongi and Adjumani.

The implementation of solar drying stands out as a direct and substantial benefit to farmers across all three districts, offering a robust solution to minimize post-harvest losses by 20% along the cassava value chain while increasing revenues by 25% at a solar drying cost of only 9% of revenues per harvest[2,8].

In turn, cooling and refrigeration technologies are particularly relevant for fresh fish and tomato traders, notably in the Adjumani and Obongi districts. A cold room is beneficial to tomato traders in Adjumani and Obongi. The cold room will reduce post-harvest losses by 30% and increase revenues by 39% at a cold room service cost of 13.6% of revenues per week.

The strategic deployment of solar-powered technologies emerges as a key recommendation to enhance overall agricultural value chain efficiency and resilience in the targeted regions.

Successful implementation, however, requires a collaborative approach with strategic planning, capacity building, and careful financial consideration to ensure economies of scale are leveraged when deploying PURE technologies.

Key Recommendations are centered around:

- actioning awareness raising and sensitization;
- forming collaborative partnerships;
- leveraging economies of scale (working with farmer groups and cooperatives is required);
- innovating business models and creating market linkages;
- conducting research and development, and ensuring effective data dissemination; and
- acting on PURE technology deployment opportunities for cassava, tomatoes and fresh fish value chains in Northern Uganda -
    - solar drying for cassava farmers
    - cold rooms for tomato and fresh fish traders
    - single use fridges for fresh fish traders

The recommendations are informed by 2,427 surveys and the business interviews conducted as part of this market assessment. Encouragingly, the grassroots views support the findings of this study.

Introduction

Adoption of solar-powered technologies such as solar dryers and cold storage units creates opportunities for economic empowerment across the value chains from farmers to traders. However, for these to be widely adopted, the development of technical local expertise, access to affordable financing solutions and enabling policies are required. [3]

This comprehensive report delves into the market dynamics of maize, cassava, sesame, tomatoes, and fish in Northern Uganda, with a particular focus on the districts of Adjumani, Obongi, and Lamwo. It provides an in-depth analysis of the current demand and supply trends in these markets, as well as the opportunities and challenges that they present.

This analysis is designed to empower PURE companies, Non-Governmental Organizations (NGOs), Government, Development Finance Institutions (DFIs) and interested stakeholders with actionable insights for informed decision-making and strategic planning in the pursuit of sustainable productive agricultural development.

The report offers a wealth of information aimed at enhancing understanding of the complexities inherent in the agricultural and aquaculture value chains in Northern Uganda. Furthermore, it incorporates key insights from technology providers to shed light on how solar cooling and drying technologies can benefit stakeholders and boost livelihoods sustainably in Northern Uganda.

Examples of solar powered technologies: a cold room (left) [9] and dryer (right) [8].

Methodology

The study was based on a context analysis drawn from a desktop and literature review that was combined with data from field surveys and business interviews conducted for the study.

The context analysis was combined with data from field surveys and data from business interviews to develop the market analysis across the five priority value chains in Northern Uganda: aquaculture/fish farming, tomatoes, cassava, sesame/simsim, and maize.

The market analysis centered around calculating the market size. Population data was used to estimate the number of fresh fish traders in Adjumani, Lamwo and Obongi districts. Average weekly fish, tomato and cassava traded volumes and prices were applied to the estimated number of traders to calculate the market size and value for Adjumani, Lamwo and Obongi.

A total of 2,427 surveys of farmers, traders and key informants were executed by AeA with analysis conducted by CREEC across the three districts of Lamwo, Obongi and Adjumani. The surveys covered both agriculture and aquaculture/fish farming and drying activities in these districts, which confirmed the key value chain actors and determined the market potential.

Business interviews were conducted with eight solar cooling and one solar drying companies operating in Kenya, Uganda and Nigeria with the aim of understanding their business models, target customers, opportunities and challenges with market adoption of the technology for application in Uganda.

Limitations and learning opportunities

- Aquaculture surveys were executed in Adjumani and Obongi due to fishing activities on the Albert Nile River, which runs through the districts. Lamwo was excluded from aquaculture surveys as no relevant literature data could be obtained.
- Solar drying technology has limited commercial adoption: the team could only locate one business to interview. Solar drying has been mainly executed by NGOs with limited success in scaling the pilots to commercial solutions.
- All post-harvest loss figures are qualitative as data is based on farmers' and traders' estimates.

Results and Market Analysis

This market analysis - based on 2,427 surveys conducted with farmers, traders and key informants in the districts of Adjumani, Obongi and Lamwo - aims to provide a comprehensive understanding of the demand and supply dynamics within the aquaculture and agriculture value chains. The analysis primarily focuses on five key value chains: maize, cassava, sesame, tomatoes, and fish [6].

The study also conducted business interviews with **eight solar cooling and one solar drying company** operating in East and West Africa.

Insights from these interviews serve to identify potential pilot partners specifically in Northern Uganda, as well as provide a deeper understanding of the opportunities and challenges early adopter PURE companies face.

The market analysis explores potential opportunities for solar cooling and drying technologies within each district in order to inform and support the AeA team to identify suitable districts for future pilots.

Farmers

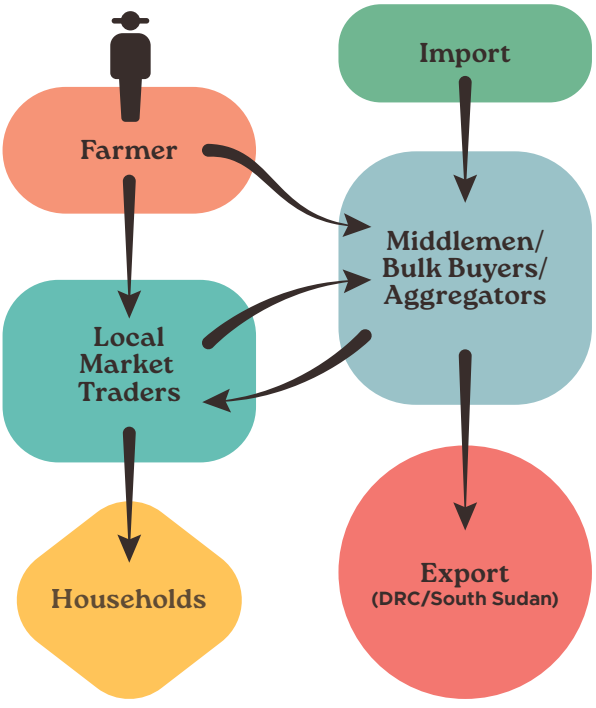

Figure 1: Stakeholders in the agriculture value chain

A stakeholder value chain map was developed based on the surveys and key informant interviews of farmers and traders.

The agricultural value chain was similar for all three districts: farmers sell primarily to local market traders and middlemen and local market traders sell to both the domestic customers and middlemen/bulk buyers for the export market. Due to high demand, certain produce are supplemented with crops from neighboring regions.

In order to understand the priority crops and grains grown by farmers we collected production data: maize, cassava, sesame, fruits and vegetables and sorghum make up the top five crop categories [11].

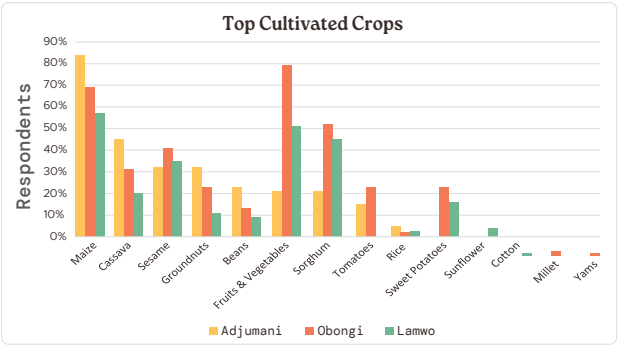

Figure 2: Crop and grain production data

In all three districts, cassava and tomatoes are the priority value chains, they are grown in the largest quantities as determined by the average production per season, measured in kilograms.

In terms of revenue, over 35% of farmers earn $100-$200 per season in Adjumani, compared to 24% and 15% in Obongi and Lamwo respectively. Most farmers fall in the $0 - $100 bracket, which indicates that they tend to engage in mixed farming at subsistence level as opposed to running commercial operations. A case in point is farm size, with an estimated half of farmers cultivating land parcels of 1-5 acres and less than 5% of farmers on land larger than 5 acres [6,11]. This limits farmers' potential yield and consequently their potential income. Seed quality, access to water for irrigation or sufficient rainfall, as well as pests and disease also impact yield [6,7,11].

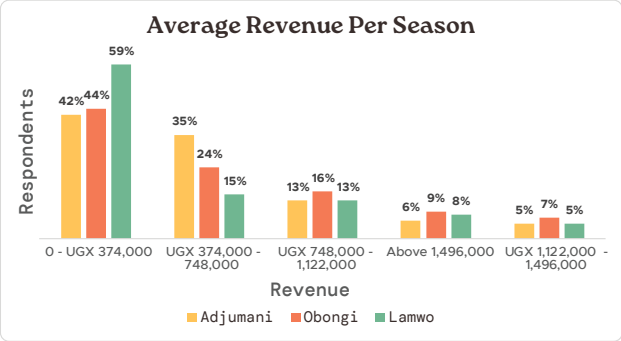

Figure 4: Average revenue per farmer per season

Most farmers indicated that they just want to earn a revenue after harvesting, while 46% of farmers in Adjumani indicated that it's **too expensive to process their crops and they don't have the resources for processing** [1,11].

Even though most farmers (78%) estimated their seasonal crop losses at no more than 20%, 19-25% of farmers believed their losses to be between 20% and 40% [4,7].

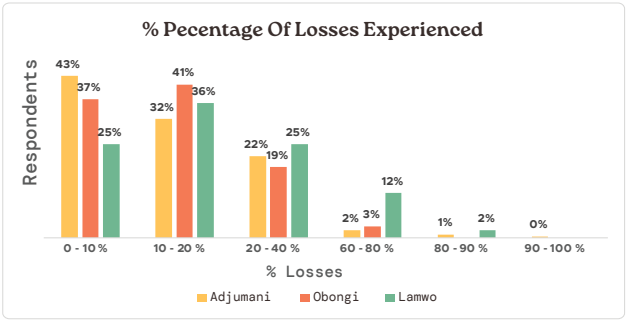

Figure 4: Post-harvest losses experienced by farmers

Farmers experiencing losses above 20% could be those growing highly perishable fruits and vegetables such as tomatoes [1].

Of all the crops, **cassava** is the **most suitable for solar drying** as it attracts a **50% higher price when dried** (UGX1,100/kg vs fresh Cassava at UGX500/kg) [2,13]. Lamwo district produces the highest quantity of cassava each season, yet over 60% of the farmers in this region earn the lowest average seasonal revenue, ranging from $0 to $100.

Farmers have little interest in solar drying: most (59% and over) use tarpaulins to air sun dry their crops while the remainder resort to air sun drying on the ground [2,7]. Interestingly, sensitization efforts are resulting in better post-harvest handling methods being adopted, yet it is important to note that close to 40% of farmers in all three districts are still drying their crops directly on the ground [2].

Table 1: Summary of impact per farmer using solar drying vs open air sun drying.

		Adjumani	Obongi	Lamwo
Open Air Sun Dried	Cassava sold (kg)	232	494	819
	Losses (%)	20%	20%	20%
	Revenue/harvest ($)	$69	$146	$244
Solar Dryer	Cassava sold (kg)	291	617	1,024
	Increased revenue/harvest ($)	$86	$183	$304
% Revenue increase		**25%**	**25%**	**25%**
% Drying Cost of Revenue		**9%**	**9%**	**6%**

Solar drying will reduce cassava farmers' crop losses by 20%, increase revenues by 25% and only cost 9% of revenues per harvest. A demonstration and sensitization campaign/pilot is required though, along with phasing this to a scaled number of farmers to make the solution sustainable [2].

Traders

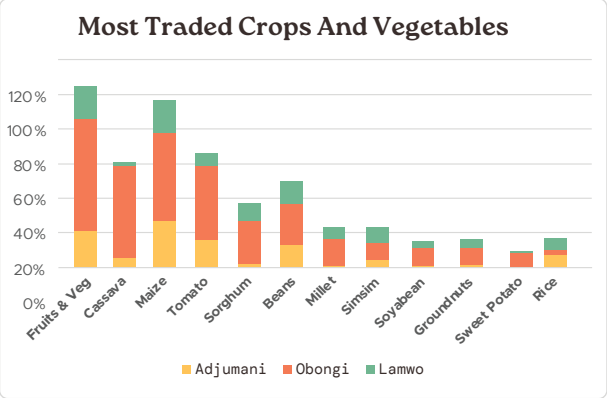

Figure 5: Most traded crop and grain by Adjumani traders

On average, the top five products sold are fruits and vegetables, cassava, maize, tomatoes and beans [5].

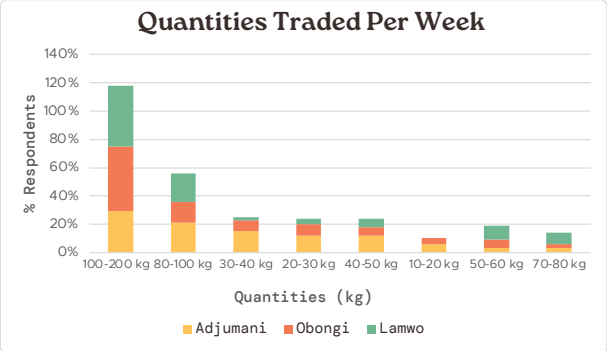

Figure 6: Quantities traded per week by traders

On average, 65% of traders prefer to sell the crops in a dried form, which makes sense for grains and legumes such as maize and cassava. Fruit and vegetables are mostly sold fresh [1,6,11].

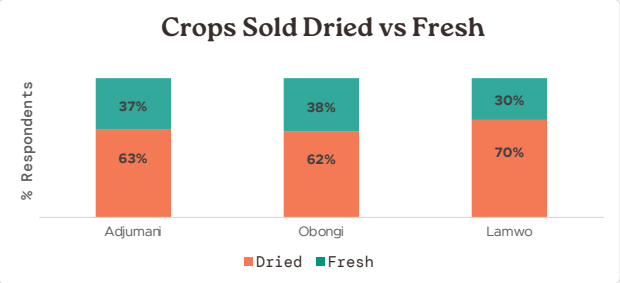

Figure 7: Percentage of crops sold dry versus fresh by traders

The main customer base of the traders are local households, who prefer milled and processed goods.

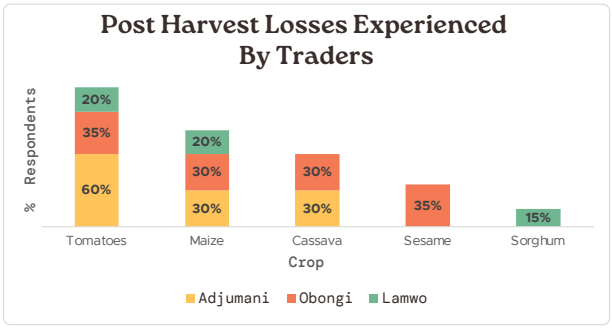

Figure 8: Post-harvest losses by Adjumani traders

Traders reported the **biggest post-harvest losses for tomatoes**, with over half of Adjumani traders citing between 30% - 60%, followed by 5% - 30% for maize and cassava. In Obongi, up to 35% of tomatoes are lost [1,4,6,7].

The prospect of a cold room is attractive.

In Adjumani, 45% of the traders indicated they would be interested in using a cold room and 40% indicated that they would be willing to pay to use a cold room. Obongi traders displayed even higher interest with almost half (49%) of those surveyed being willing to use and pay for a cold room[14].

In Lamwo, the low interest in using and paying for a cold room may be due to the lower volumes of tomato trade compared to Obongi and Adjumani. Lamwo traders may also not fully understand a cold room's potential benefits, which could be resolved through awareness raising and sensitization with a demonstration/pilot of the technology.

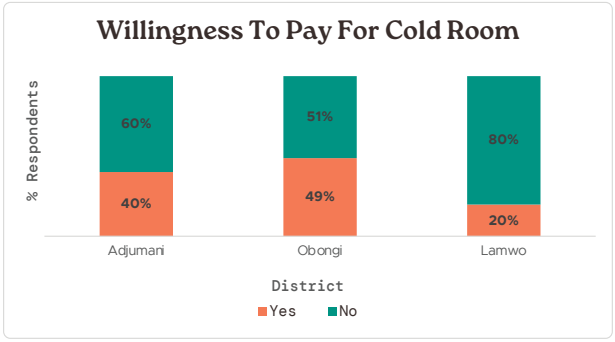

Figure 9: Willingness to pay and use a cold room in Adjumani

Encouragingly, 51% of traders would pay to use a cold room, and would be willing to pay more than the minimum rate required to justify the construction of the cold room.

Of the Adjumani traders who are willing to pay for use of a cold room, 97% would be willing to pay between $0.27-$5/day. Of the equivalent group in Obongi, 13% are willing to pay between $5.4-$13.5/day, while in Lamwo traders would pay $0.27-$5/day. Compare this to the estimated minimum rate required to cover the cold room cost of $0.32/25kg per crate per day.

A simple business case illustrates the potential impact of cold rooms on market traders, increasing revenues by 39% on tomatoes at a cost of $0.32 per 25kg per day. This would be highly achievable in Adjumani and Obongi [14].

Table 2: Tomato business case illustrating potential of a cold room

		Adjumani	Obongi	Lamwo
Cold room use	Revenue per week per trader using cold room	$ 65.81	$ 65.81	$ 26.32
	Cold room cost per week per trader	$ 8.96	$ 8.96	$ 3.58
	Profit per week per trader	$ 56.85	$ 56.85	$ 22.74
No cold room	Revenue per week per trader	$ 47.30	$ 47.30	$ 21.62
	Post-harvest losses	30%	28%	20%
% Revenue increase		39%	39%	22%

As noted, a sensitization and awareness raising campaign that includes demonstration and proof of concept should improve demand in Lamwo.

Aquaculture/Fish farming

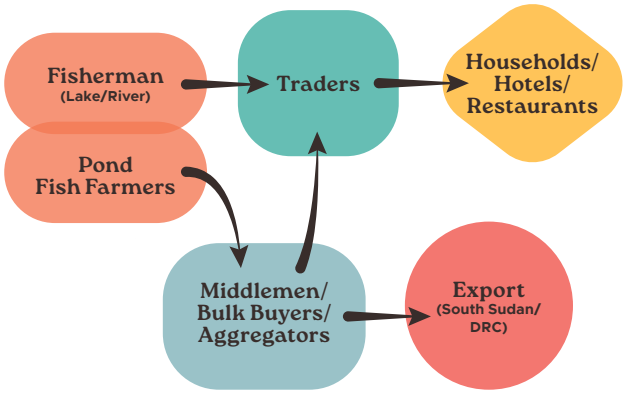

Figure 10: Fresh fish value chain stakeholders in Adjumani and Obongi

Fresh fish traders in Adjumani and Obongi source their fish mainly from fishermen harvesting from the lake and river (Albert Nile), as well as from middlemen. Traders sell mainly to the local domestic market where households are the main customers, while middlemen / bulk buyers sell to the export market [10].

[1] https://data.unhcr.org/fr/country/uga

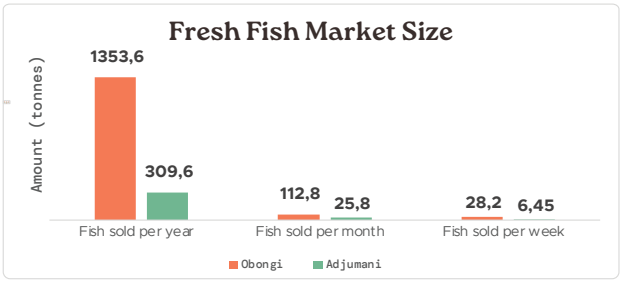

Figure 11: Obongi and Adjumani fresh fish market size

The size and value of the fresh fish market was determined with the help of a model based on UNHCR [1] population figures.

With an estimated 340 fresh fish traders in Adjumani and 140 in Obongi, the projected size of the fresh fish market is 1,354 tonnes a year for Adjumani and 309.6 tonnes a year for Obongi respectively. Adjumani's fresh fish market is therefore 4.37 times larger than that of Obongi [10].

This values the fresh fish market in Adjumani at $1,936,789 and that in Obongi at $729,174 per annum.

Table 3: Market Value determined for fresh fish in Obongi and Adjumani[2].

		Obongi	Adjumani
Market Value	Average price $/kg	$2.36	$1.43
	Revenue per week $	$15,191	$ 40,350
	Revenue per month $	$60,764	$ 161,399
	Revenue per year $	$729,174	$ 1,936,789

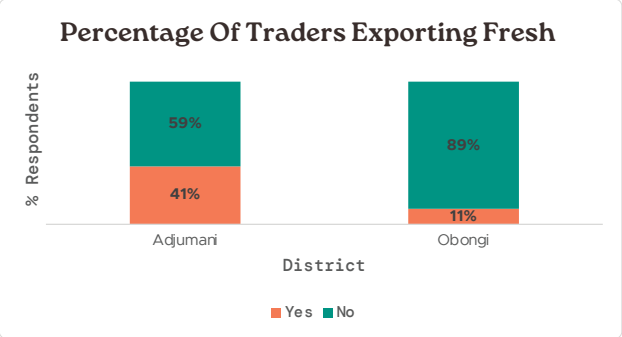

Figure 12: Percentage of fish being exported by traders

Fish is mostly sold locally, with 41% of fish traded in Adjumani exported to mainly the DRC and South Sudan [10].

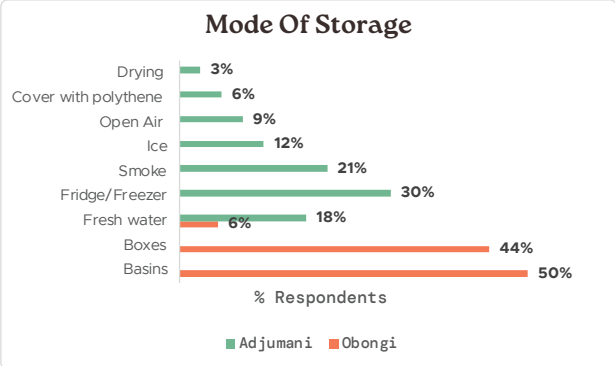

Figure 13: Mode of fresh fish storage in Adjumani and Obongi

Storage facilities in Obongi market consist almost exclusively of rudimentary boxes and basins. About a third of Adjumani traders use a fridge or freezer [10,14,18].

Interest in fridges is high.

In Adjumani, 91% of traders reported that they would be interested in acquiring a fridge, with 99% of them indicating they would store the fridge at the market (ideally a cold room). Similarly, in Obongi, 86% of traders were interested in obtaining a fridge.

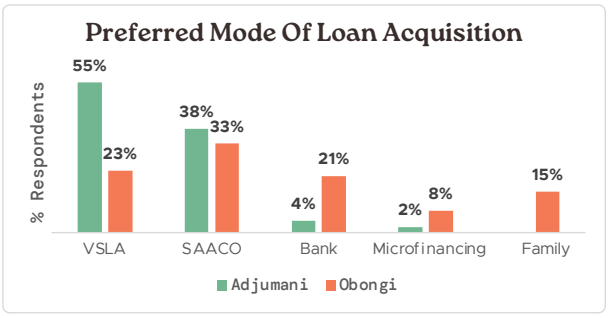

Figure 14: Preferred method to acquire a loan by traders

The two most preferred methods to obtain a loan for a single unit fridge are through a Savings and Credit Co-operative (SAACO) or Village Savings and Loan Association (VSLA) [14,18].

Fish traders across both districts can afford solar fridges on a PayGo model as the weekly loan service fee of $8 is less than 10% of weekly revenues earned by fish traders.

Table 4: Affordability of solar fridges on PayGo by fish traders.

	Cost
Average weekly revenue per trader	$148
Pay as you go down payment	$95
Weekly payment over 18-24 months	$8

[2] Table 3 Revenue values are based on Figure 11: weekly, monthly and yearly tonnage values.

Dried Fish Traders

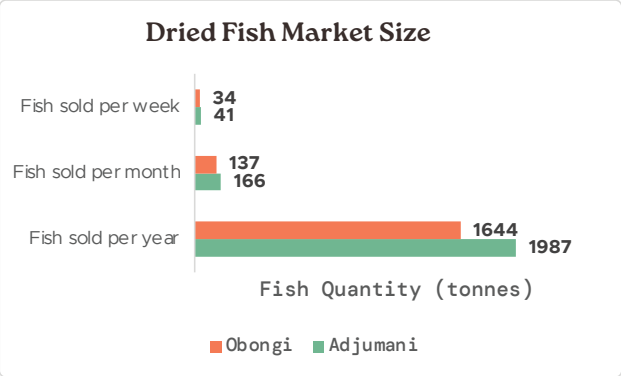

Figure 15: Adjumani and Obongi dried/smoked fish market size

As in the case of the fresh fish analysis, 98% of the smoked and dried fish traded at Adjumani market is sold locally with only 2% being exported, compared to 54% of local sales in Obongi. **The Ugandan market cannot satisfy the high export demand of smoked fish to DRC and South Sudan** [10].

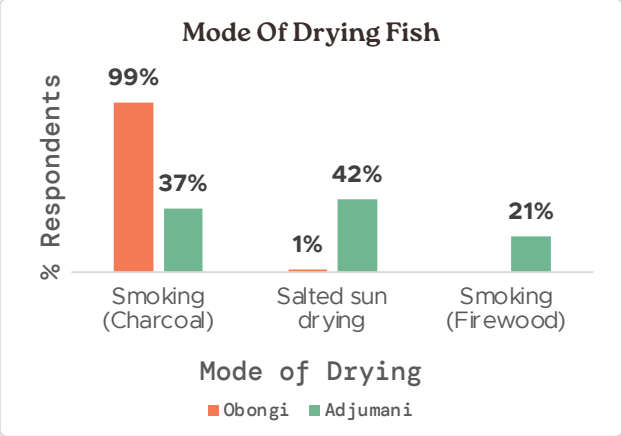

Figure 16: Methods of drying the fish

The age-old, traditional methods of salting and smoking to preserve fish still yield good results[10]. It takes roughly 24 hours to smoke fish both in Adjumani and Obongi, and costs between 5,000 - 10,000 UGX per week. There is a high demand for smoked fish, especially smoked Catfish for DRC.

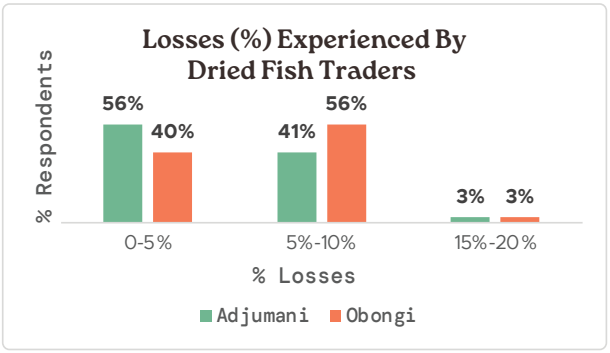

Figure 17: Post-harvest losses by dried and smoked fish traders in Adjumani and Obongi

Post-harvest losses are generally low among dried fish farmers in both Adjumani and Obongi as only 3% of the traders in both districts reported losses above 10% [7,10]. There is, however, a notable interest in solar dryers among traders, with 55% of Adjumani traders and 90% of Obongi traders expressing interest in the technology respectively.

The market has a preference for smoked fish, and while there is a market for salted dried fish, the survey indicates that these numbers are low. Given the equally low post-harvest losses (5 - 10%) and the minimal increase in weekly revenue, the high upfront capital expenditure of over $2,000 for solar drying is not justifiable, making solar drying an unsuitable technology option for drying fish [10].

Businesses

Summary of interviews with businesses offering Solar Cooling and Drying for Agriculture and Fish Farming

This section provides a summary of the **business interviews conducted with eight solar cooling and one solar drying company** operating in East and West Africa. The interview insights serve to identify potential pilot partners specifically in Northern Uganda, as well as allow for a deeper understanding of the opportunities and challenges early adopter PURE companies face.

PURE companies interviewed	a. Solar Cooling Engineering b. EcoLife	a. Ecotutu	SureChill	Village Energy Bright Life Kool Box Kuza Freezer	Kaspheryn Ecolife
Technology	**Cold walk-in room manufacturers and suppliers**	**Cold walk-in room distributors and operators**	**Solar refrigeration technology suppliers and manufacturers**	**Solar refrigeration, single units**	**Solar dryers**
Description of technology	a. Technology developers/ manufacturers provide technical design support to distribution partners of containerized cold room technology (movable). b. Passive cold room technology design with solar and fabrication using bricks and mortar (fixed).	a. Containerized solar walk -in cold room (movable). b. Passive cold room technology design with solar and fabrication using bricks and mortar (fixed).	Single unit DC solar refrigeration manufacturers of technology.	Single unit DC solar refrigeration distributors.	**Parabola** - permanent structure that is more efficient and can handle large volumes (fixed). **Box** - smaller system (movable).
Business models	a. B2B - Builds relationships with distributors and develops a payment plan (90% upfront CAPEX provided by distributors; 10% balance paid after 2 months). b. Outright purchase	a. Cooling as service - Asset is managed and owned by a cold room distributor with a daily service fee per kg charged to end-users b. Outright purchase	a. B2B - Builds relationships with distributors and develops a payment plan (90% upfront CAPEX provided by distributors; 10% balance paid after 2 months). b. Outright purchase	a. PayGo b. Outright purchase c. Lease to own	a. Outright purchase
Cost of technology	**Depends on size:** a. **Containerized walk-in cold room** $4,500-$7,000 b. **Estimated CAPEX cost** $8,000 - $12,000	**Fruit and veg cold rooms** - $0.32 per 25kg crate per day (market areas) **Meat cold rooms** City $0.52 - $0.64/kg Rural areas $ 0.39-$0.52/kg **Outright purchase** (12x12x8m cold room weighing 5 ton) $18,000 - $21,000	**Outright purchase** $1,000- $1,500	**PayGo** $100 deposit or 15%-35% down payment and weekly payments of $7-$10.5 over 15-24 month loan repayment period. **Lease to Own** Initial payment of $140, then $2.50/day for 15 months. **Outright purchase** $1,000 - $4,000	**Parabola** $7,853-$14,396 **Box** $1,963-$3,272
Clients - main off-takers of technology	a. Distributors	Market traders of fruit and veg and meat	Distributors	Primarily small shops selling cold drinks, dairy farmers and traders, fish traders	Farmer cooperatives and processors

Solar Cold Rooms and Refrigeration

Solar Drying

Opportunities

Standards and Quality Controls

- Develop standards and quality controls (in progress, led by Verasol and CLASP for solar fridges).

Technology Reach

- Solar Cooling to expand services to dairy, fish and veterinary medication.

Financing and Partnerships

- Climate Finance could be a catalyst to unlock much-needed financing but requires a clear carbon credits structure.

Environmental Sustainability and Resilience

- Solar refrigeration aligns with global and national efforts to cut carbon emissions and combat climate change.

Rural Electrification

- Solar refrigeration can help electrify remote areas where traditional grid infrastructure is absent or unreliable, improving people's lives and supporting business activities.

Market Potential

- There is growing market potential for preserving agricultural produce using solar cooling and drying.

Standard and Quality Controls

- Develop standards and quality controls for solar dryers.
- Solar dryers preserve the natural color, taste, fragrance, and nutrients of the produce, while shelf life is extended to more than a year.

Technology Reach

- Solar drying has the potential to reach farmers and enable them to add value and increase farmer revenues.

Financing and Partnerships

- Working with cooperatives or a group of farmers allows for costs to be shared, making the technology more accessible and affordable.
- Solar drying is beneficial for the cassava and fruit value chains. Developing commercial applications of the technology can attract financing.
- Financing an organized group such as a cooperative will have a high likelihood of success than financing individual farmers with no scale.

Job Creation

- More than 12 jobs are created per solar dryer deployed.

Community Impact

- Enables farmers to dry and increase the shelf life of products, increasing their overall yield to market and obtaining higher prices for the dried product, resulting in higher revenues for farmers.

Challenges

Tax and Financial Challenges

- Limited tax incentives overall.
- DC solar fridges have high costs due to limited subsidies, limited economies of scale and full taxation on the fridge as it is deemed a luxury item.
- Customers find the price point challenging, low interest debt or CAPEX support is required from Donors.

Technology and Awareness

- Customer awareness of the technology is limited, and some have a negative perception of solar due to past experiences with substandard products.
- Raising awareness is a critical step to increase adoption but places additional resource constraints on PURE companies.

Logistical and Operational Challenges

- Logistics is a challenge, specifically to transport fridges requires care.
- Low understanding of the market as data is limited.

Technical Challenges

- Lack of critical infrastructure and skilled personnel required for proper installation, maintenance, and repair.

Skill and Training Requirements

- Quality design and engineering skills are needed to develop and implement cold rooms. Training and building the technical skills of staff will be critical in the servicing and deployment of cold rooms.

Tax and Financial Challenges

- The upfront cost of solar dryers can be challenging for many users.
- No tax incentives but grants on pilots have been executed in Uganda, Nigeria and Benin.

Technology and Awareness

- Solar drying is low tech but requires engineering design and skilled application during installation.
- Need for awareness-raising and training about the benefits and operation of solar dryers. Lack of knowledge can hinder adoption.

Logistical and Operational Challenges

- Commercial operation and market penetration required to justify development of local and skilled tradesmen to service and maintain solar dryers.

Technical Challenges

- Lack of skilled personnel and engineering design required for proper installation, maintenance and repair.

Skill and Training Requirements

- Quality design and engineering skills are needed to develop and implement efficient solar dryers.

Identifying the Right Value Chain

- Determining the appropriate value chain for solar drying requires a deep understanding of both the technology, the agricultural products, local practices, and the market.

SWOT Analysis

The following high level SWOT analysis informs decision making around the adoption of solar cooling or drying technologies.

Strengths

Energy independence and rural electrification:
Solar cooling and drying technologies provide energy independence, thereby reducing vulnerability to fluctuating fuel prices or supply disruptions. It can also service un-electrified areas.

Environmental sustainability:
These technologies align with global and local efforts to cut carbon emissions and combat climate change.

Long-term cost savings:
While the initial investment is relatively high, the long-term operational and maintenance costs are lower due to free and abundant solar energy.

Weaknesses

High initial costs:
The initial costs of purchasing and installing these systems can be prohibitively expensive for many users.

Technical challenges:
Ensuring quality and efficiency of these relatively new and evolving systems is critical to gaining consumer trust.

Skill requirements:
Providing after sales service and maintenance of these systems require specialized skills and training.

Data and information
on value chains and market sizing is limited.

Market awareness and readiness:
Awareness of the technology is low with demonstration pilots together with awareness raising and sensitization campaigns required before commercial deployment is considered.

Opportunities

Job creation:
Solar cooling and drying technologies present a great opportunity for local job creation.

Skills development:
Opportunity for individuals to learn and develop new skills related to PURE technologies.

Market potential:
There is a growing market potential for preserving agricultural produce using PURE technologies.

Threats

Regulatory challenges:
Inconsistent or unclear regulations related to solar energy can impede adoption and scalability.

Financial challenges:
Accessing debt for these technologies can be challenging due to various financial situations in different countries.

Reputation risk:
Solar technology has a bad reputation due to inferior products that entered the market in the past. This could affect the adoption of solar cooling and drying technologies.

Gap analysis

The assessment of market potential and size, particularly in the agricultural sector, remains a significant challenge due to the high prevalence of subsistence farming. The **lack of data and detailed value chain analysis for PURE** makes it difficult to accurately gauge the true market appetite for technologies such as solar drying and cooling. The sustainability of solar drying technology is uncertain, primarily because the majority of projects are pilot initiatives reliant on grant funding rather than established, self-sustaining models [3,4,11,12].

Key Insights and Recommendations

The adoption of solar drying and cold room technologies presents a significant opportunity to enhance agricultural productivity while increasing revenues for farmers and traders in Adjumani, Obongi, and Lamwo.

Solar drying will directly benefit cassava farmers across all three districts, especially in Lamwo where the highest production of cassava was confirmed. Solar drying will reduce post-harvest losses by 20% and increase revenues by 25% at a solar drying cost of only 9% of revenues per harvest [2,13].

Cooling technologies such as cold rooms and single fridges primarily benefit traders through reducing post-harvest losses forfresh fish. A cold room is beneficial to tomato traders in Adjumani and Obongi. The cold room will reduce post-harvest losses by 30% and increase revenues by 39% at a cold room service cost of 13.6% of revenues per week [14,15].

The table below summarizes the key insights and recommendations for Adjumani, Obongi and Lamwo with regards to solar cooling and drying based on the market analysis findings.

Table 4: Key insights and recommendations for Adjumani, Obongi and Lamwo with regards to solar cooling and drying

	Targeted Beneficiaries	Pure Technology	Crops	Adjumani	Obongi	Lamwo	Proceed with a pilot
Agriculture	Farmers	**Solar dryer** deployed at a cooperative level	Cassava	**291 kg** per season	**617 kg** per season	**1 ton** per season Highest for cassava production and requires 345 farmers to participate	YES
Agriculture	Traders	**Cold room**	Tomatoes	High interest **100-200 kg** per week of trading	High interest **100-200 kg** per week of trading	Low interest/High losses Low tomato trading of **30-40 kg** per week	YES
Aquaculture	Fresh fish traders	**Cold rooms** and **single unit fridges**	Fresh fish	High interest	High interest	N/A	YES
Aquaculture	Dried fish traders	**None**	N/A	High preference for smoked fish			NO

Successful implementation, however, requires a collaborative approach with strategic planning, capacity building, and careful financial considerations to ensure economies of scale are leveraged.

Partnerships with PURE technology providers and financial institutions are required and must entail: awareness campaigns, training programs, and engaging policy makers to develop favorable policies. Developing a pilot that is collaborative and educational will lead to success in the promotion and uptake of PURE technologies. While solar drying and cooling technologies have high upfront costs, innovative financing models and favorable tax incentives make them more affordable for end users, which is the case for solar cooling technologies [3]. Therefore, a multi-faceted approach involving various stakeholders can ensure the successful rollout of PURE technologies, leading to sustainable agricultural practices and improved livelihoods for farmers and traders in Northern Uganda.

The Key Recommendations are to:

- **Raise Awareness**

  Sensitize farmers, traders, extension officers and policy makers about the benefits of solar-powered drying and cooling systems through educational campaigns, demonstrations and outreach programs.

- **Build Collaborative Partnerships**

  Encourage partnerships between government agencies, private sector entities, NGOs, and international organizations. This will help create a comprehensive ecosystem for solar-powered solutions in agriculture and address the enabling environment required to support the uptake of these technologies.

- **Enabling Environment Required to support uptake of PURE**

  Developing the right policy incentives for PURE is critical to drive adoption of PURE technologies in Uganda. There are no incentives for solar drying technologies while cooling receives a partial tax incentive. These incentives are crucial in building the market and aiding in affordability to the end-users.

- **Innovate Business Models and Create Market Linkages**

  Develop innovative business models such as pay-go or “energy as a service”, where users only pay for what they use, to make PURE technology more affordable and accessible.

  Identify opportunities to deploy PURE technologies in agriculture, and actively **establish market linkages** between smallholder farmers and PURE companies and bulk-buyers/traders to ensure adoption and sustainability of solar-powered cooling and drying systems.

- **Drive Sectoral Research and Development, and Data Dissemination**

  Conduct further research and development to understand the market opportunity for PURE technologies in the aquaculture and dairy sectors of Northern Uganda. Data is limited on, for example, environmental conditions, specific crop types, and market dynamics.

  Provide access to and disseminate data to all actors in the value chain - from smallholder farmers and traders to PURE companies and Government officials. Making the data accessible and open source is needed to drive adoption of PURE.

- **Pursue Northern Uganda Market Analysis Opportunity**

  Leverage the confluence of factors that make a fertile test bed for detailed, real life market analysis.

  Cassava, tomatoes and fresh fish present key opportunities for adopting PURE technologies as it can add value, increase skills and capacity, and create jobs based on the market analysis developed. Lamwo further presents an opportunity for cassava and sesame solar drying, milling and oil processing.

These recommendations aim to address the challenges associated with adopting PURE technologies and ensure that farmers and traders in Northern Uganda can reap the maximum benefits from solar drying and cold rooms.

Conclusion

Following our comprehensive analysis, we propose the development of both cold rooms and single solar fridge pilots in Adjumani and Obongi. Furthermore, we suggest advancing cassava drying using solar drying in all three districts: Adjumani, Obongi, and Lamwo.

The **cold rooms should primarily serve market traders involved in the tomato value chains and fresh fish trade** in Adjumani and Obongi. We encourage Ayuda en Acción to engage with the following technology partners:

- Ecotutu and Ecolife (both cold room developers and operators who formed part of the business interviews), to progress a cold room pilot in Adjumani; and Obongi
- Bright Life and Sure Chill, to progress solar single unit fridges for fresh fish farmers in Obongi and Adjumani.

Solar drying directly impacts farmers' livelihoods and is best deployed to groups of farmers[3]. The dryer's size will determine its cost, and therefore the number of farmers in the group and the amount of produce each farmer should dry to make its installation viable.

Solar drying in particular requires collaboration and partnerships to both prepare the market and support - from sensitization and incentives to skills development - to ensure successful adoption.

On the one hand, engaging with the Ministry of Energy and Mineral Development (MEMD) and Ministry of Agriculture, Animal Industries and Forestry (MAAIF) on the impacts of solar drying will pave the way for the development of solar tax incentives and garner support for agricultural programmes to raise awareness around the benefits of PURE to users. **Awareness raising is a task that must be led by Government, NGOs, DFIs. This cannot be left to the private sector companies alone.**

Sharing the detailed context and market analysis with PURE technology providers and partners is a critical first step for them to develop sound business and technical solutions, including quality products, initially for a pilot but also for the ongoing expansion of PURE technologies in Northern Uganda.

Ayuda en Acción should support the pilot with market linkages as well as the crucial task of creating demand by educating end users about the benefits of using PURE technologies.

Lamwo opportunity

Interestingly, Lamwo presents an additional advantage in that it already has 25 mini grids operated by Winch Energy, which provides opportunity for PURE collaboration with Ayuda en Acción (AeA). Aside from cassava, solar dryers could also be used for maize and sesame, while milling and oil processing are additional value adding activities. **Other value chains such as milk and tomatoes could be evaluated for leveraging the mini-grids' power for PURE applications.** Adding post-harvest processing technologies will add to the customer base, thereby contributing to consistent revenue for the mini-grid operator [3,18]. In turn, this will help ensure reliable energy supply for both the community and productive applications.

[3] Cooperatives will be key in establishing relationships with farmers when deploying solar drying technology for cassava farmers[2,13].

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