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POWER AFRICA NIGERIA POWER SECTOR PROGRAM PRODUCTIVE USE COLD STORAGE SYSTEMS IN NIGERIA

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Contracting Officer's Representative: Narlene Egu

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ACRONYMS

Acronym	Definition
ABP	Anchor Borrowers' Program
ACGS	Agricultural Credit Guarantee Scheme
ACSS	Agricultural Credit Support Scheme
ADB	Asian Development Bank
AFD	French Development Agency
AfDB	African Development Bank
AGSMEIS	Agric-Business/Small and Medium Enterprise Investment Scheme
B	Breadth
BAU	Business As Usual
BOA	Bank of Agriculture
BOI	Bank of Industry
BRAC	Bangladesh Rural Advancement Committee
C&I	Commercial and Industrial
CACS	Commercial Agriculture Credit Scheme
CBN	Central Bank of Nigeria
CFC	Chlorofluorocarbon
tCO ₂ e	Tons of carbon dioxide equivalent
COVID-19	Coronavirus Disease
CSS	Cold Storage System
DBN	Development Bank of Nigeria
DFI	Development Finance Institution
DSCR	Debt-Service Coverage Ratio
EnDev	Energizing Development
FAO	Food and Agricultural Organization of the United Nations
FCDO	Foreign, Commonwealth and Development Office
FFV	Fresh Fruits and Vegetables
GAIN	Global Alliance for Improved Nutrition
GHI	Global Hunger Index
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
GOGLA	Global Off-Grid Lighting Association
GWP	Global Warming Potential
H	Height
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HCFCs	Hydrochlorofluorocarbons
HFO	Hydrofluoroolefin
IAAS	Ice-as-a-service
IFS	International Food Standards
IRR	Internal Rate of Return

L	Length
l	Liters
LAPO	Lift Above Poverty Organization
MGPP	Mini-Grid Partnership
MSMEs	Micro and Small and Medium-sized Enterprises
NEP	Nigerian Electrification Project
NEXIM	Nigerian Export-Import Bank
NPV	Net Present Value
ODSs	Ozone Depleting Substances
P-AADS	Private Sector-Led Accelerated Agriculture Development Scheme
PA-NPSP	Power Africa Nigeria Power Sector Program
PAYS	Pay as you store
PFI	Private Finance Institutions
PHL	Post-Harvest Losses
PLAN	Postharvest loss alliance for nutrition
PUF	Polyurethane Foam
RBF	Result based financing
REA	Rural Electrification Agency
REEP	Renewable Energy and Energy Efficiency Partnership
REF	Rural Electrification Fund
RMI	Rocky Mountain Institute
ROI	Return on investment
SAM	Severe Acute Malnutrition
SAS	Stand Alone Solar
SHS	Solar Home Systems
SMEDAN	Small and Medium Enterprises Development Agency of Nigeria
SPCC	Solar Powered Cold Storage System
TAGE	TransAfrica Gas and Electric
TES	Thermal Energy Storage
TSS	Thermal Storage System
UNICEF	United Nations International Children's Emergency Fund
US	United States
USADF	United States African Development Foundation
USAID	United States Agency for International Development
US\$	US Dollar
US\$FC	United States International Development Finance Corporation
UV	Ultraviolet light
VCA	Value Chain Analysis

EXECUTIVE SUMMARY

Nigeria's agriculture sector loses an estimated NGN 110 trillion (US\$268 billion) to post-harvest losses (PHL) annually, due to inadequate cold storage, agro-processing, and transportation infrastructure available to farmers, fishermen, and retailers.¹ The impact of inadequate cold storage is mostly observed for highly perishable food commodities such as dairy, fish, fruits, and vegetables. Solar-powered cold storage systems (SPCSS) provide a reliable and cost-effective cold storage option for agricultural stakeholders, by leveraging clean and sustainable solar energy. PA-NPSP conducted a scenario analysis to analyze the costs and benefits for financing for SPCSS. Some of the key insights drawn from this exercise include:

- Depending on the business model, powering option and cold storage system, the economic viability of SPCSS investment varies.
- Under the debt financing structure, SPCSS investment is more profitable than diesel powered cold systems.
- SPCSS users can save up to 10% of powering costs if cold storage equipment is powered by a solar-diesel hybrid system rather than a diesel generator.
- Grants and equity are particularly necessary to decrease the loan amounts borrowed to cover the capital cost for solar-powered cold room investments.

To encourage sustainable deployment of SPCSS in Nigeria, PA-NPSP recommends the following based on a thorough literature review and scenario analysis:

- **Consideration of environmental impacts of cold storage technologies:** In order to maintain environmental sustainability, SPCSS users, as well as donors and governments funding SPCSS, should be cognizant of the Global Warming Potential (GWP) of refrigerants associated with different cold storage options, comparing Hydrofluoroolefin (HFO), blended hydrofluorocarbons (HFCs), ammonia, and CO₂ with traditional hydrochlorofluorocarbons (HCFCs), and HFCs.
- **Understanding of costs, benefits, and deployment models:** When assessing the best deployment model for investing in and implementing SPCSS, users and funders should take due consideration of pay as you store (PAYS) rates, operating costs such as fuel requirements, and escalation costs. Some models may require high PAYS rates to achieve financial viability and these rates must be validated with customer willingness to pay before an investment decision is made.
- **Awareness campaigns:** Given the complex nature and high number of different cold storage systems, it is necessary that users and customers are equipped with relevant knowledge of costs, potential benefits, suitability, deployment models, and financing options to allow for sound decision making.
- **Targeted financing and awareness campaigns for marginalized customers:** Governments and donor funded programs can mitigate gender imbalance or imbalance impacting other marginalized groups through strategic awareness campaigns for these populations. Such entities can also offer specialized financing opportunities specifically for women who are 13x less likely to own land (critical collateral for accessing loans).
- **Further analysis of location-specific business models:** There is an opportunity for the off-grid stakeholder community to further develop location specific, data-driven business models for cold storage given different states require different types of cold storage, based on the type of commodities produced and transported.

¹ Estimate based on an estimated 20% PHL savings for milk and 40 percent PHL savings on fish, fruits, and vegetables on annual food production rate. See Table 2.

Each of these is explored and supported in each section of the report. The report includes an introduction, an overview of the need for solar powered cold storage in Nigeria and market potential, a detailed review of solar powered cold storage systems and deployment models, a discussion of financing options, a scenario analysis exploring outcomes and sensitivities of different variables to solar powered cold storage deployment, and a conclusion summarizing insights from the literature review and scenario analysis.

INTRODUCTION

Each year, Nigeria's agriculture sector loses an estimated NGN 110 trillion (US\$268 billion) to post-harvest losses (PHL) due to lack of adequate storage, agro-processing, and transportation infrastructure available to farmers, fishermen and retailers.² There is a high demand for both stationary and mobile cold storage systems, from farms to markets, due to the combination of high temperatures — that accelerate the rate of spoilage — long distances traveled, and the extended time spent in transit due to poor road conditions).³ These losses are especially severe in the long-haul transport of fruits and vegetables, of which half of the total post-harvest losses (PHL) (up to 60%) occur during transportation.^{4, 5} It is estimated that 41% of the tomatoes lost post-harvest are damaged or perish in transit.⁶ The significant food losses inevitably result in a reduction in the quantity of nutritious foodstuffs available in the market.

Solar-powered cold storage systems (SPCSS) provide adequate storage means for agricultural stakeholders by leveraging clean, sustainable solar energy. However, many stakeholders lack the knowledge and financial support required to leverage solar-powered cold storage systems.

This study by the Power Africa – Nigeria Power Sector Program (PA-NPSP) seeks to achieve the following objectives:

- Provide an overview of the market for solar-powered cold storage systems
- Identify the benefits, challenges, current environment, and opportunities for growth
- Offers recommendations for sustainable deployment for SPCSS

METHODOLOGY

This study evaluates different investment case scenarios using techno-economic analysis to discover the economic viability of solar-powered cold storage systems and business models suitable for rural farmers, fishermen, Micro, Small and Medium Enterprises (MSME), mini-grid developers, and entrepreneurs. This includes a financial analysis of eight scenarios, under four distinct business models: pay-as-you-store (PAYS), ice-as-a-service (IAAS), commercial partner or shared community-owned (a debt financed investment for community use, to be operated and maintained by the community). The analysis focuses on six cold storage systems of varying capacities for the preservation of milk, fish, meat, fresh fruits and vegetables (FFVs), and ice production.

To support this analysis, desk research included over 100 primary literature sources; documented in Appendix D. In addition, interviews were conducted to validate the study assumptions with over 10 organizations in Nigeria across the off-grid energy and agriculture sectors, including private sector companies, non-governmental organizations, donor agencies, financial institutions, and government agencies.

² Estimate based on an estimated 20% PHL savings for milk and 40 percent PHL savings on fish, fruits, and vegetables on annual food production rate. See Table 2.

³ Bolarin, F. M. and Bosa, S. O. (2015). "Post-Harvest Losses: A Dilemma in Ensuring Food Security in Nigeria". Journal of Natural Sciences Research Volume 5, Number 7. Source: Post Harvest Losses: A Dilemma in Ensuring Food ... - IISTE <https://www.iiste.org › JNSR › article › download>

⁴ Food and Agricultural Organization of the United Nations (FAO) Nigeria Country Office (undated). Strengthening Nigeria's plantain value chain to curtail post-harvest losses. Source: <http://www.fao.org/3/i4123e/i4123e.pdf>

⁵ Centre for the Promotion of Imports from Developing Countries (CBI) Ministry of Foreign Affairs of The Netherlands (2021). "Food Loss in Nigeria: Value Chain Analysis (VCA) of Tomato, Onion, Chili value chains". Source: <https://www.rvo.nl/sites/default/files/2021/02/Report-Food-Loss-in-Nigeria.pdf>

⁶ World Bank (2020). Nigeria: Food Smart Country Diagnostic". Source: <https://openknowledge.worldbank.org/bitstream/handle/10986/34522/Nigeria-Food-Smart-Country-Diagnostic.pdf?sequence=1&isAllowed=y>

REPORT STRUCTURE

The main body of the report summarizes the study, and a series of appendices provide greater depth of analysis and additional data. This report is divided into the following sections:

- **Introduction:** This section provides an overview of post-harvest losses (PHL) in Nigeria, the report objectives, the methodological approach, and indicates the focus of the analysis.
- **The Need for Cold Storage Systems:** This section discusses multiple factors that necessitate the use of, as well as drive the demand for, cold storage technologies. It also highlights the benefits of cold storage to farmers and agribusinesses.
- **Market Potential of Cold Storage in Nigeria:** This section analyzes the market potential of cold storage for fish, milk, and fruit and vegetable products in Nigeria. It identifies the degree to which these perishable income-generating produce require cold storage solutions.
- **Cold Storage Systems:** This section discusses the different types of cold storage technologies used both in Nigeria and globally. It also considers the obstacles facing the adoption of cold storage systems across Nigeria.
- **Deployment Models:** This section explains the different models through which cold storage systems can be adopted by agricultural stakeholders and identifies the advantages and disadvantages of each model.
- **Financing Options and Potential Partnership Opportunities:** This section looks at the possible sources of financing and opportunities for partnerships available to those seeking to acquire cold storage systems.
- **Cold Storage Business Case Analysis:** This section evaluates the economic viability of solar-powered cold storage systems (SPCSS) based on financial analysis of eleven scenarios, under widespread business models, along with the methodology and assumptions used to prepare these financial models.
- **Recommendations:** This section provides recommendations necessary to encourage the sustainable deployment of SPCSS in Nigeria, based on this study's findings.

THE NEED FOR COLD STORAGE SYSTEMS

There are several providers of cold chain equipment and facilities currently in operation in Nigeria due to the high level of demand for both stationary cold storage facilities, and cold storage transport and logistics. According to a capacity mapping carried out by the Global Alliance for Improved Nutrition (GAIN) between December 2017 and February 2018, the cold chain storage capacity of Lagos State alone was an estimated 200,000m³.⁷ However, information on the distribution of cold chain facilities and service providers in Nigeria is limited, partly due to the refusal of businesses to disclose such information.⁶

Most of the cold storage services that are available are primarily for the preservation of meat and fish, with comparatively few options suitable for the storage of fresh fruits and vegetables (FFV), and milk.⁶ Where these options exist, they provide immediate and significant benefits for the farmers and agribusinesses utilizing them.

The preservation of food commodities is connected to the following factors which together drive the business case for increasing the deployment and adoption of cold storage in Nigeria:

- Improved income
- Prevention of food scarcity and improving export potential
- Proliferation of markets and supermarkets
- Deployment of energy access business models

In Nigeria, access to constant and reliable electricity is a major challenge for target customers situated within unelectrified and underserved communities. Due to unreliable grid electricity, most cold storage systems in existence are powered by diesel generators, leading to high operating costs and environmental pollution. Alternatively, cold storage systems can be powered by solar systems or solar-diesel hybrid systems, which offer the double advantage of a low cost and low-emission.

IMPROVED INCOME

Cold storage systems help users preserve their farm-produce, which translates to increased incomes by as much as 50%.⁸ By extending the preservation of produce, farmers are able to negotiate better prices for a higher quality product, leading to revenue gains and accrual of income.

For example, in a rural farming community, a small collective of 10 pastoral farmers produce 100kg of milk monthly (excluding PHL), generating a total revenue of NGN 72,034 (US\$174.83) per month.⁹ Considering post-harvest losses of 20% due to inadequate cold storage, this amounts to a loss of NGN 14,407 (US\$34.96) per month due to the unavailability of milk chilling options. However, with the introduction of chilling facilities, these farmers will earn that additional NGN 14,407 (US\$34.96) per month, bringing their monthly total to NGN 86,441 (US\$209.80).

FOOD SCARCITY AND EXPORT POTENTIAL

At its current population growth rate, Nigeria's population is forecasted to double to 400 million by 2050.¹⁰ It is therefore imperative that food production and supply rise to keep pace with demand. In Nigeria, as much as 20 – 30% of total grain production, 30 – 50% of root and tuber, and around 30 – 50% of FFVs are lost during the post-harvest stage, due to poor processing, marketing, distribution, and storage

⁷ Global Alliance for Improved Nutrition (GAIN), and The Rockefeller Foundation (2018). "Nigeria cold chain capacity mapping-postharvest loss alliance for nutrition (PLAN)". Source: <https://www.gainhealth.org/resources/reports-and-publications/nigeria-cold-chain-capacity-mapping-postharvest-loss-alliance>

⁸ BASE (2020). "Reducing Food Waste and Vaccine Spoilage through Cooling Solutions". Source: <https://energy-base.org/news/reducing-food-waste-and-vaccine-degradation-through-caas/>

⁹ Expatistan (2021). Cost of Living: Nigeria. Source: <https://www.expatistan.com/price/milk/lagos>

¹⁰ The Economist (2020). "Africa's population will double by 2050". Source: <https://www.economist.com/special-report/2020/03/26/africas-population-will-double-by-2050>

facilities.¹¹ To mitigate food shortage and increase the present availability of food, Nigeria has relied heavily on imported produce to supplement local production. Table I includes information on the amount of money spent on importing produce in the FFV, dairy, and fish market segments. The current levels of food commodity importing represents a significant market opportunity for reducing PHL of farm produce in Nigeria.

Table I: Food Commodity Import and Export Value (2019)

Food Commodity	Export Value (NGN)¹²	Import Value (NGN)¹³
Cashew	2,784,546	75,014,056
Orange	2,546,340	1,152,418,733
Mango	3,277,386	111,146,893
Tomato	174,958	70,690,585
Milk	192,603,515	3,135,666,923
Fish	390,166,232	33,430,101,940
Total	591,552,977	37,975,039,130

Therefore, solutions aimed at preserving the freshness of produce are all the more crucial since the reduction in food loss directly results in an increase in the amount of food available, thereby reducing the overreliance on imports as well as the level of undernourishment in the country.¹⁴ The pertinence of the latter issue in Nigeria is evident in the Global Hunger Index (GHI) ranking the country 98th out of the 107 graded countries, with a score of 29.2 indicating that hunger is a serious issue.¹⁵ The United Nations International Children’s Emergency Fund (UNICEF) estimated that approximately 2 million children suffer from severe acute malnutrition (SAM), and with 32% of children below the age of five years old suffering from stunted growth, Nigeria has the second highest burden of stunted children worldwide.¹⁶ This is further corroborated by the 2018 Global Nutrition Report, which reports a total of 13.9 million stunted

¹¹ Miyinyawa Yahaya (2002). Farm structures, Ibadan Press, 32-37.

¹² OEC (2019). Nigeria (NGA) Exports, Imports and Trade Partners. Source: <https://oec.world/en/profile/country/nga#economic-complexity>

¹³ TrendEconomy (2021). Nigeria – Imports and Exports. Source: <https://trendeconomy.com/data/h2/Nigeria/0801>

¹⁴ World Bank (2020). Nigeria: Food Smart Country Diagnostic”. Source: <https://openknowledge.worldbank.org/bitstream/handle/10986/34522/Nigeria-Food-Smart-Country-Diagnostic.pdf?sequence=1&isAllowed=y>

¹⁵ Global Hunger Index (GHI) (2020). “2020 Global Hunger Index by Severity”. Source: <https://www.globalhungerindex.org/ranking.html>

¹⁶ United Nations International Children’s Emergency Fund (UNICEF) Nigeria (2019). Nutrition. Source: <https://www.unicef.org/nigeria/nutrition>

children in Nigeria, and the 2020 edition reporting levels as high as 40% in Jigawa State.¹⁷¹⁸ Investments in cold chain facilities will have a significant positive impact on this situation as they have the potential to increase food supply and drive down prices. FAO points out the positive impact on women due to the additional opportunities made available by cold chains, especially in the fishing industry.¹⁹

Reduced food wastage will also improve Nigeria's trade deficit. The Federal Government of Nigeria is already implementing policies aimed at developing its agricultural sector to make the country less dependent on foreign countries for food. The Agriculture Promotion Policy 2016-2020 (APP) was developed to provide solutions to the country's challenges in meeting its domestic food demand, as well as boosting the profitability of its export market.²⁰ Cold storage systems will facilitate the success of this initiative and will generate greater revenue inflows for the national economy through increased export volumes.

Table I also illustrates the export values of certain FFVs in Nigeria, which could substantially increase with a wider implementation of cold storage systems across the country. Furthermore, the potential boost in the availability of produce will have an appreciable impact on national GDP and the economy through a rise in exports. With the annual exports generating almost US\$600 million, an increase in the volume of exports will result in a direct increase in export revenue generated. This additional financial inflow is valuable to the Nigerian government in its attempts to improve its balance of trade. According to Statista, the last time Nigeria made a surplus in its trade balance was in 2019 of US\$7.27 billion.²¹ In 2020, there was a deficit of US\$22.07 billion.²²

PROLIFERATION OF MARKETS AND SUPERMARKETS

Since the turn of the millennium, Nigeria has experienced an explosion in the creation of markets and urban supermarkets. According to the National Bureau of Statistics (NBS), the percentage of total GDP attributed to the wholesale and retail trade sector increased steadily during the early years of the second decade of the 2000s, accounting for 15.58% in 2011, 17.05% in 2012 and 18.44% in 2013.²³ While the fallout of the 2016 recession, as well as the recent economic hardship and uncertainty, have somewhat hampered the growth of the supermarket sector (it accounted for 16.7% of GDP in 2018), it has still experienced a meteoric rise over the past two decades.²⁴ This has been largely due to the rapid urbanization and population growth experienced in the country. Nigeria's population has increased steadily over the last 20 years from 122 million by 2000, to 159 million by 2010 and to over 200 million by 2020.²⁵ Inevitably the demand for food has risen exponentially, which has necessitated the growth of the food retail sector and, in turn, heightened the need for cold storage options in order to ensure food security. Furthermore, the emergence and growth of a middle class in Nigeria has fueled the proliferation of supermarkets across the country. The previous decade of relative political stability, high oil prices, rising GDP and higher per capita income created avenues for economic growth and development in Nigeria,

¹⁷ The 2018 Global Nutrition Report. Source: <https://globalnutritionreport.org/reports/global-nutrition-report-2018/burden-malnutrition/>

¹⁸ The 2020 Global Nutrition Report. Source: <https://globalnutritionreport.org/reports/2020-global-nutrition-report/inequalities-global-burden-malnutrition/>

¹⁹ Food and Agriculture Organization of the United Nations, "Food Loss and Waste in Fish Value Chains." Source: <http://www.fao.org/flw-in-fish-value-chains/value-chain/processing-storage/cold-storage/equitable-social-gender-environment/en/>

²⁰ Dr Heineken Lokpobiri (2019). "Nigerian Agriculture Promotion Policy 2016 – 2020: Towards a New Paradigm for Domestic Food Security and Foreign Exchange Earnings in Agricultural Production". Public Policy and Administration Research 9(3), 47-57.

²¹ Statista. Source: <https://www.statista.com/statistics/383170/trade-balance-of-nigeria/>

²² Ibid.

²³ Business Day Newspaper (2016). Nigerian Retail Sector Report 2014/2015. Source: <https://businessday.ng/wp-content/uploads/2016/10/Nigeria-Retail-Sector-Report-2014-.pdf>

²⁴ Nigeria Food and Beverage Industry Report 2018. Source: <https://www.slideshare.net/fabwestafrica/nigeria-food-and-beverage-industry-report-2018>

²⁵ The World Bank (2020). Population total, Nigeria. Source: <https://data.worldbank.org/indicator/SP.POP.TOTL?locations=NG>

which has resulted in more consumers being attracted to the more modern and organized supermarkets in comparison to traditional market settings. Additionally, the rate of rural-urban migration has increased significantly over time, with many rural dwellers relocating to urban areas in search of better job and living prospects. According to World Bank data, the urban population in Nigeria is currently 52% of its total population, up from approximately 35% in the year 2000.²⁶ Since almost all the food grown in Nigeria is produced in rural areas, the need for cold storage equipment and facilities to preserve perishable produce being transported to urban areas cannot be understated.

DEPLOYMENT OF ENERGY ACCESS BUSINESS MODELS

Solar-powered mini-grids and Stand-Alone Systems (SAS) are primary renewable energy technologies which supply power to off-grid locations. This provides the opportunity for a low-emission, cost-efficient cold storage system, compared to diesel powered systems.

The SAS sector has witnessed significant growth evidenced through increased sales, about 324,000 SAS units were sold in 2019, up from negligible sales five years earlier.²⁷

As of 2020, Nigeria has an estimated installed mini-grid capacity of 2.8MW, with 59 mini-grid project sites serving rural consumers out of which 52 are solar powered. These are mostly residential-based mini-grids with some developed for specific productive uses. An increasing number of developers are seeking opportunities to supply commercial and industrial (C&I) customers or other business customers with large predictable loads while also using the mini-grid to provide electricity to residential customers. This increases the utilization rate of the mini-grids, reduces risk through predictable loads, lowers the cost of electricity, and increases profits for the developer.²⁸

Cold storage systems are potential anchor loads that can be powered by mini-grids. Anchor loads are continuous, predictable loads (use of electricity) with potential to increase the utilization rate of mini-grids, thus lowering the cost of electricity and increasing profits for the developer. There is a reduced burden (both financial and technical) on users who can power their cold storage systems via mini-grids. While a cold storage system acts as an “anchor load”, in some instances there may be a need for an additional storage system that can sustain cooling when electricity cannot be supplied by the mini-grid (further discussed in this report).

Many conventional cold storage systems in Nigeria are heavily reliant on diesel generators and consume copious amounts of diesel in the process of powering the equipment. This contributes to climate change due to the carbon emission level of diesel fuel.²⁹ This impact is compounded by rising global temperatures, which is one of the greatest threats to future food security and further increases the need for cold storage options to preserve food. This could also result in the creation of a negative spiral in which the need for these carbon-intensive cooling systems further exacerbates climate change, which subsequently drives up the demand for cooling solutions even further. Solar powered cold storage provides an alternative to diesel powered equipment achieving the same result without emitting greenhouse gas emissions.

²⁶ World Bank (2020). Urban population (% of total population) – Nigeria. Source: <https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=NG>

²⁷ Stand-alone Off-grid Solar Market Research: Nigeria (2021). ACETAF, TetraTech, UK Aid. Source: <https://www.ace-taf.org/wp-content/uploads/2021/05/ACE-NIGERIA-MARKET-RESEARCH-STAND-ALONE-OFF-GRID-SOLAR-FINAL-REPORT.pdf>

²⁸ Mini-Grid Partnership (MGPP), BloombergNEF and Sustainable Energy for All (2020). “State of the Global Mini-grids Market Report: Trends of renewable energy hybrid mini grids in Sub Saharan Africa, Asia and island nations. Source: https://minigrids.org/wp-content/uploads/2020/06/Mini-grids_Market_Report-20.pdf

²⁹ US Energy Information Agency (EIA) (2016). “How much carbon dioxide is produced when different fuels are burned?”. Source: <https://www.eia.gov/tools/faqs/faq.php?id=73&t=11>

Figure I: Potential Emissions Reductions from Switching to Solar Cold Storage³⁰

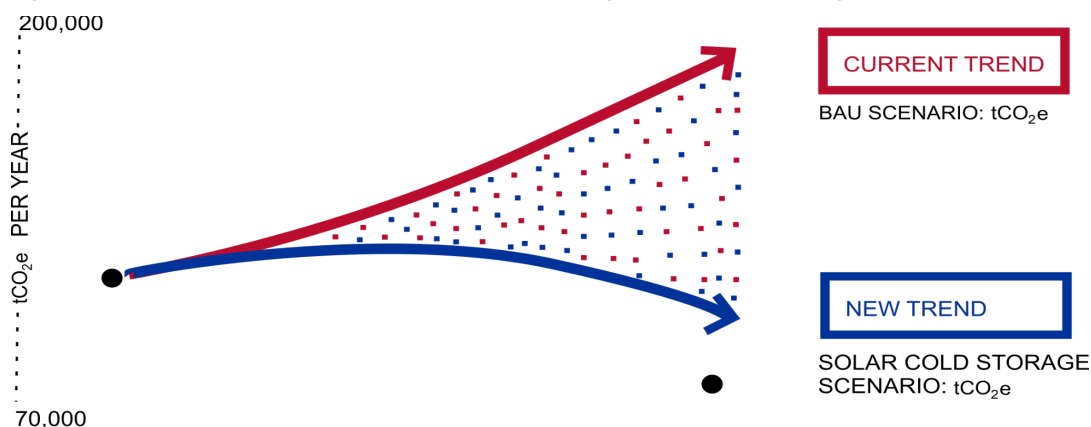


Figure I represents the expected impact of introducing solar-powered multi-use agricultural cooling on the carbon emissions arising from agricultural activities in Uganda. Continuing the Business As Usual (BAU) trend leads to a continuous rise in the emissions of carbon dioxide equivalent (tCO₂e), further exacerbating the climate emergency.

COLD STORAGE MARKET POTENTIAL IN NIGERIA

According to official estimates by the Food and Agriculture Organization of the United Nations (FAO), global post-harvest losses (PHL) can reach up to 20% for cereals, 30% for dairy and fish, and 40% for fruit and vegetables.³¹ This level of waste is devastating, particularly in Africa where approximately 250 million people (20% of the continent’s population) are undernourished.³² In Sub-Saharan Africa, for example, an estimated US\$4 billion worth of food, which could feed over 48 million people, is lost every year due to post-harvest losses.³³

Data collected from primary and secondary sources revealed that cold storage systems are available and operational across Nigeria. However, when compared to the number of farmers and agribusinesses who need this technology, there is a severe gap between the demand and supply of cold storage in Nigeria. This gap is pronounced in rural communities where the overwhelming majority of smallholder farmers lack access to cold storage solutions.³⁴ PHL estimates as well as the size of the agriculture industry indicate a sizable potential to scale deployment of SPCSS, which is expected to have a significant impact for highly perishable food commodities such as dairy, seafood, fruits, and vegetables, with inadequate cold storage. The following discussions lay out the significance and drivers for each of these, followed by Table 2, at the end of this section providing an estimate of potential reduction in PHL for these.

Fish Storage: The fishing industry in Nigeria is in dire need of cold storage solutions due to the high perishability of fish, as well as low and sometimes sub-zero temperature storage requirements. Thirty to

³⁰ The Renewable Energy and Energy Efficiency Partnership (REEP) (2017). “Solar Powered Multi-Use Cold Storage in Uganda: Station Energy”. Source: <https://www.reeep.org/projects/solar-powered-multi-use-cold-storage-uganda-station-energy>

³¹ Food and Agricultural Organization of the United Nations (FAO) (2019). “Reducing post-harvest losses”. Source: <http://www.fao.org/3/ca6344en/ca6344en.pdf>

³² Food and Agricultural Organization of the United Nations (FAO) (2020). “The State of Food Security and Nutrition in the World 2020”. Source: <http://www.fao.org/3/ca9692en/online/ca9692en.html>

³³ Food and Agricultural Organization of the United Nations (FAO) (2020). “Food losses increase during COVID-19, a major hurdle to Africa’s development”. Source: <http://www.fao.org/africa/news/detail-news/en/c/1310100/>

³⁴ Kibiti, B. and Strubenhoff, H. (2019). “How off-grid cold storage systems can help farmers reduce post-harvest losses”. Brookings. Source: <https://www.brookings.edu/blog/future-development/2019/10/16/how-off-grid-cold-storage-systems-can-help-farmers-reduce-post-harvest-losses/>

fifty percent of harvested fish is lost due to inadequate cold storage.³⁵ Fish is integral to diets in Nigeria with the average Nigerian consuming 13.3kg of fish per year.³⁶ The combination of the dominance of traditional fish preservation practices (such as fish smoking), the dearth of cold chain infrastructure, and consumers' strong preference for fresh fish pose major obstacles to implementing mini-grids for the purpose of fish refrigeration and freezing.³⁷ If unable to introduce these cold storage solutions, fish farmers miss a great opportunity to increase their revenue through reducing post-harvest losses of fish and selling their fish in markets far from the point of capture using cold transport vehicles. Interviews in *PA-NPSP's Productive Use Stimulation in Nigeria: Value Chain & Mini-grid Feasibility Study* revealed all aquaculture value chain participants expressed their belief that refrigeration would allow them to sell more fresh fish as opposed to smoked fish, despite their lack of experience with cold storage.³⁴

Milk Storage: According to International Food Standards (IFS), milk is one of the most perishable protein commodities, requiring cooling at approximately 10°C within 3-4 hours of collection to prevent spoilage. Conservative calculations estimate the post-harvest losses of milk at 20%, which is costly because the degraded milk is unfit for use and often discarded except in instances where it can be used to make cheese.³⁴ The high perishability of milk requires significant energy resources to meet cooling requirements in Nigeria where the average cow can produce 213kg of milk in a year. Furthermore, due to the integral role of dairy farming in the cultures and economies of certain regions of Nigeria, it is unsurprising that some milk chilling operations receive hundreds of liters of milk daily from pastoral farmers.³⁴ For example, dairy cold chain services in the Middle-Belt and Northern Nigeria, home to many livestock farmers, tend to experience high levels of milk production. This creates an avenue to leverage the concentration of dairy farming activities into the development of the productive use of energy through partnerships with existing dairy off-takers who seek to expand their local milk supply chain.³⁴

One example of milk chilling facilities yielding immediate and substantial dividends to its users is found in the creation of the Milky Way Partnership in Kaduna State. It is a collaboration between a Danish dairy company called Arla Foods, the Kaduna State Government, a local dairy cooperative called Milcopal, and local dairy farmers which was created to boost both the Nigerian dairy market as well as the livelihoods of local dairy farmers.³⁴ The provision of milk chilling facilities was vital to this partnership because it is through the preservation of locally sourced milk that Arla Foods is able to support the development of the fast-growing Nigerian dairy industry, and because the facilities provide opportunities for local dairy farmers to generate higher and more stable incomes from their activities.³⁴ This partnership has been beneficial to all parties as the dairy farmers have been provided with permanent grazing lands for their cattle by Kaduna State Government, while Arla Foods has access to a constant source of locally produced milk. This is an example of a combination of the commercial partner model and community-owned model, discussed later in this report under the section on the deployment models.

Fruits & Vegetable Storage: There is a large variety of fruits and vegetables grown across Nigeria, and they are produced in enormous quantities, as shown in Table 2 . Over 10 million metric tons of FFVs are produced annually for domestic consumption and export, with some of the main products including: mango, pepper, citrus, tomato, banana, plantain, okra, and onions. There is significant potential for the industrial use of the by-products of FFVs but they require adequate preservation until use. For example, high value components such as nutrients extracted from produce can be made into substances and food additives that aid digestion, regulate blood pressure, improve bowel movement, and can serve as colorants,

³⁵ Adeyeye, S. A. O. (2016). "Traditional Fish Processing in Nigeria: A Critical Review". *Nutrition & Food Science*, 46(3) 321-335. Source: <https://doi.org/10.1108/NFS-11-2015-0148>

³⁶ Food and Agricultural Organization of the United Nations (FAO) (2017). "Fishery and Aquaculture Country Profiles: The Federal Republic of Nigeria". Source: <http://www.fao.org/fishery/facp/nga/en>

³⁷ Santana, S.; Allee, A.; Meng, Z.; Omonuwa, W.; Sherwood, J.; Balaji, M. K.; Rosi-Schumacher, K. (2020). "Agricultural Productive Use Stimulation in Nigeria: Value Chain & Mini-Grid Feasibility Study". Rocky Mountain Institute, Deloitte Consulting LLP. Prepared for the U.S. Agency for International Development Power Africa Nigeria Power Sector Program.

antioxidants, and flavorings.^{38,39} Capitalizing on these additional benefits of fruits and vegetables would significantly contribute towards an acceleration in the rate of advancement of the Nigerian processing industries. However, despite the wide variety of produce and the abundance of opportunity, there is a severe lack of large-scale fruit and vegetable industries in the country.⁴⁰ Furthermore, due to the high perishability of these food items, a significant percentage is lost due to inefficient handling and storage. Therefore, it will be highly advantageous to both the Nigerian economy and society if greater effort is invested into the growth and development of fruit and vegetable industries to take advantage of the abundance of available produce, thereby greatly reducing PHL.

The potential annual savings on PHL for fish, milk, and some FFVs based on the estimates shown in Table 2 is approximately NGN 110 trillion (US\$268 billion), which emphasizes the need for accessible and effective storage facilities and underlines the market potential for new or existing entrants into the cold storage market.

Table 2: Cold Storage Market Potential

Market Segment	Annual Production (metric ton)	Price per metric ton (NGN)	Potential Annual Savings (NGN M)
Cashew	960,000	525,000	201,600
Orange	4,160,000	25,000	41,600
Tomato	3,816,009	370,660	565,776
Milk	523,599,000 ⁴¹	720,344 ⁴²	113,151,419
Fish	1,100,000	1,000,000	330,000
Total	534,581,704	--	110,776,845

*Based on an estimated 20% PHL savings for milk and 40% PHL savings on fish, fruits, and vegetables.

³⁸ Gowe, C. (2015). "Review on Potential Use of Fruit and Vegetables By-Products as A Valuable Source of Natural Food Additives". Food Science and Quality Management, 45, 47-61.

³⁹ Ahmad, F. and Khan, S. T. (2019). Potential Industrial Use of Compounds from By-Products of Fruits and Vegetables. In A. Malik, Z. Erginkaya, and H. Erten (Eds.), Health and Safety Aspects of Food Processing Technologies.

⁴⁰ Alagba, R.; Ofor, M. O.; Okoli, N.; Ibeawuchi, I. I.; and Obiefuna, J. C. (2015). "Fruit and Vegetable Crop Production in Nigeria: The Gains, Challenges and The Way Forward". Journal of Biology, Agriculture and Healthcare 5(2), 194-208
Source: https://www.researchgate.net/publication/332876077_Fruit_and_Vegetable_Crop_Production_in_Nigeria_The_Gains_Challenges_and_The_Way_Forward/link/602661f792851c4ed567214b/download

⁴¹ Knoema (2019). Nigeria - Production of milk. Source: <https://knoema.com/atlas/Nigeria/topics/Agriculture/Live-Stock-Production-Production-Quantity/Production-of-milk>

⁴² Expatistan (2021). Cost of Living: Nigeria. Source: <https://www.expistan.com/price/milk/lagos>

COLD STORAGE SYSTEMS

The preservation methods of refrigeration and freezing are vital parts of the food chain and vary by food product. Chilling temperatures vary between 0°C to 8°C whereas freezing temperatures are below -18°C.

Examples of cold storage systems used around the world include cold rooms, industrial blast freezers, milk chillers, refrigerators, mobile refrigerated trailers, and ice makers. The different options are designed to cater to the context-specific needs of customers, which vary depending on the products being stored, the intended duration of storage, and the existing energy situation of the target customers locations. These systems can be powered by diesel, solar energy systems or solar-diesel hybrid systems either through dedicated stand-alone power generation or power from mini-grids serving a larger community in that area. There is a high operational cost and capital cost associated with powering cold storage solutions using diesel generators and solar systems, respectively. This section provides a description of each of the types of systems with examples of their deployment. Table 4 at the end of this section presents the applicability of each of them to the various value chains and typical capacities. A business case scenario analysis, in a later section of this report, evaluates which powering options are most suitable, economically.

Benefits of cold storage systems adopted in several countries have been observed to preserve income-generating farm-produce, increase revenue, and create jobs. Appendix A summarizes additional information on cold storage services employed by farmers and agribusinesses in different parts of the world. Included are cold storage facilities in Nigeria, Ghana, India, and Rwanda. Products range from stationary cold rooms used to store FFVs to milk chillers and other solutions designed to meet preservation and cold storage needs.

COLD ROOMS

Cold rooms are stationary temperature-controlled rooms used to store fresh fruits and vegetables to significantly extend freshness and quality. The capacity varies depending on the size of the storage unit. There are smaller, more compact units targeted at smallholder farmers in rural areas, and there are much bigger units utilized by large agribusinesses and food processors. The temperature of cold rooms can vary depending on the specific storage requirement of the farm-produce.

An example of a cold room provider is ColdHubs, which provides plug-and-play modular, solar-powered walk-in cold rooms for 24/7 off-grid storage and preservation of perishable foods that can extend the shelf life of FFVs from 2 days to 21 days.⁴³ The cold rooms deployed by ColdHubs possess the following features:

- Operate at a maintained temperature of 5°C.
- Stainless steel floors made with 0.8 – 1mm aluminum to prevent slippage and rust
- Energy efficient mono-block refrigeration unit with the environmentally friendly R290 propane refrigerant connected to a set of inverters and batteries that supply energy
- Batteries charged by solar panels, which generate about 5.7 kWh of energy.
- Capacity for 2000 – 3000kg (2-3 metric tons) of perishable food arranged in at least 150 units of 30kg (0.03 metric tons) plastic crates
- The units can either be leased to farmers who run it and are paid a commission per crate used or purchased by a farmer's cooperative under a subsidized repayment plan.⁴⁴

⁴³ ColdHubs. Source: <https://www.coldhubs.com>

⁴⁴ CNN (2015). "A radio show host may have fixed Nigeria's worst problem." Source: <https://edition.cnn.com/2015/12/22/africa/cold-hubs/index.html>

Figure 2: ColdHubs Modular Walk-in Cold Room



Another provider is InspiraFarms, which provides cold storage options in Africa as well as in Asia, Central America and South America.⁴⁵ The organization is focused on designing, developing, and supplying modular and energy-efficient cold rooms and packhouses that are either on or close to farms in emerging markets.⁴⁶ With the current deployment of its on-demand model in Mexico, Ethiopia, and Mozambique, more than 5,000 members of rural communities in developing countries have experienced improved livelihoods, especially the women in underserved communities that now have jobs.⁴² InspiraFarms expects each unit to potentially increase the net income of over 200 small-scale producers by over 30% due to the significant reductions in PHL and increased quality of produce.⁴²

One of InspiraFarms' clients is Ausmoz Farm holdings, which is a commercial farm in Mozambique that has invested in cold rooms to preserve the freshness of litchis (lychees) produced for export.⁴⁷ Initially, Ausmoz invested in refrigerated containers to store the fruits before they were exported, but a surge in production over the past three years meant that their existing facilities were no longer sufficient to satisfy their storage needs. This led to the produce being spoiled and wasted, which resulted in considerable financial losses for Ausmoz. In response to this, Ausmoz invested in a modular cold room, which can store a maximum of 20 metric tons of produce. The facility is equipped with pre-cooling capabilities through air-forced cooling and a humidifier, which rapidly lowers the fruit's pulp temperature to preserve optimal quality.⁴⁴

INDUSTRIAL BLAST FREEZER

The industrial blast freezer is a specialized stationary freezer used to preserve food at sub-zero degrees Celsius temperatures to prevent the growth of harmful bacteria that spoils food. Blast freezers work by blowing chilled air from blowers mounted inside the freezer that rapidly reduces the temperature of the

⁴⁵ The Shell Foundation (2019). The 'Cold Chain' Opportunity: Reducing Postharvest Losses and Increasing Market Access for Rural Farmers. Source: https://shellfoundation.org/feature_posts/the-cold-chain-opportunity/#_ftn1

⁴⁶ InspiraFarms. Source: <https://www.inspirafarms.com>

⁴⁷ Ausmoz Farm holdings (2021). Source: <https://www.inspirafarms.com/portfolio-items/ausmoz-farm-holdings-mozambique/>

food.⁴⁸ These form smaller ice crystals within the food items than conventional freezing, thereby causing less damage and thus preserving the quality longer. Blast freezing ensures that the food preserves its taste and texture when it thaws and is primarily used by businesses in the frozen food industry to store vegetables, fresh fish, or raw meat that must be stored at very low temperatures. This technology is especially useful for areas of intermittent power supply as the frozen items will remain cold for hours in the absence of further cooling. The capacity varies depending on the size of the storage unit.

Figure 3: Standard Blast Freezer Diagram⁴⁹



An example of a blast chiller supplier is De Koolar Nigeria Limited. Their units are powered by grid connection or diesel generators or solar energy systems. They also provide units of various sizes upon request and deliver them across Nigeria. Another example is Eja-Ice Nigeria Limited, they offer solar-powered freezers with natural refrigerants to fish retailers through affordable lease-to-own schemes.

MILK CHILLER

Milk chillers reduce the temperature of milk and keep it at a very low temperature preventing deterioration of milk molecules. This preserves milk and extends storage life, which allows for time to transport it to users.

An example of a milk chiller service provider is Promethean Power Systems, a company based in India. Its systems employ thermal energy storage, which stores cold energy as opposed to electricity, under its patented “Promethean Thermal Storage System (TSS)” to chill the stored milk.⁵⁰ The milk chilling process includes three core components with an optional fourth component available as a complementary piece (Table 3).

⁴⁸ ADK Kooling Ltd (2016). “A Brief Look at Blast Freezers and Understanding its Working Principle”. Source: <https://adk.co.uk/brief-look-blast-freezers-understanding-working-principle/>

⁴⁹ Alvin, L. (2017). Blast Freezer - A Hygienic and Affordable Way of Freezing Food. Medium. Source: <https://medium.com/@Refrigeration/blast-freezer-a-hygienic-and-affordable-way-of-freezing-food-aa50285e3a4>

⁵⁰ Promethean Power Systems. Source: <https://cooelectrica.com>

Table 3: Promethean Power Systems' Milk Chiller Components⁵¹

Milk Heat Exchanger	
Flow rate: 35°C - 4°C (can be customized)	210 liters/hour
Holding Funnel Capacity	60 liters
Dimensions (L x B x H)	0.76 x 0.76 x 1.7 meters
Designed Ambient Temperature	40°C
Heat surface exchange	1.2 square meters
Thermal Storage System (TSS)	
Number of TSS	1
Back-Up Capacity	500 liters
Time to Recharge	4 - 5 hours
Dimensions	1.2 x 1.2 meters
Chiller Unit (for charging TSS)	
Compressor Type	Copeland Scroll
Refrigerant	R-404 a
Power input	3.5 kW
Average Cooling Capacity	5 kW
AC Power Supply	220 / 50 Volt/Hz
Milk Cooling Tank (Optional)	
Capacity	1000 liters
Maximum capacity	1100 liters
Polyurethane foam (PUF) Insulation	50 mm
Dimensions	1.96 x 1.08 x 1.35 meters

Rural dairy farmers in India are heavily impacted by the country's unreliable power supply as it severely limits their access to cooling solutions. This situation is exacerbated by the reluctance of dairies to operate in rural areas due to the high cost of installing milk chillers.⁵² With no way of transporting their milk to large dairies, the farmers are forced to either sell to local markets and risk spoilage, or sell to middlemen who take a cut from the proceeds.⁴⁹ This is vital for the country's dairy industry, which accounts for 22% of global milk production and makes India the largest producer of milk in the world.⁵³ It is also a key contributor to the rural Indian economy as it is a significant source of employment and income.

Promethean Power Systems has sold several units to its dairy partners in India, Sri Lanka and Bangladesh, and has installed 25 units in Bangladesh for the Bangladesh Rural Advancement Committee (BRAC), which is the world's largest NGO.⁵⁴ To date, the company has installed 1,200 units, which has served 60,000 dairy farmers, chilled 700 million liters of milk, and saved 3 million liters of diesel.⁴⁷ Furthermore, there is a 30-40% increase in the volume of milk collection when a village-level chilling center is installed because doing so makes the collection process more streamlined.⁵¹ This undoubtedly provides immediate benefits to individual dairy farmers as it increases their revenue generation, raises their profit margins, advances their agribusinesses thus improving their overall living standards. Many of them are the community-owned model.

⁵¹ Engineering for Change (2020). Promethean Power Systems. Source: <https://www.engineeringforchange.org/solutions/product/promethean-rapid-milk-chiller/>

⁵² Forbes India (2019). "Promethean Power: A chill pill for dairy farmers". <https://www.forbesindia.com/article/innovation-factories/promethean-power-a-chill-pill-for-dairy-farmers/53087/1>

⁵³ Food and Agricultural organization of the United Nations (FAO) (2021). "Gateway to dairy production and products". Source: <http://www.fao.org/dairy-production-products/production/en/>

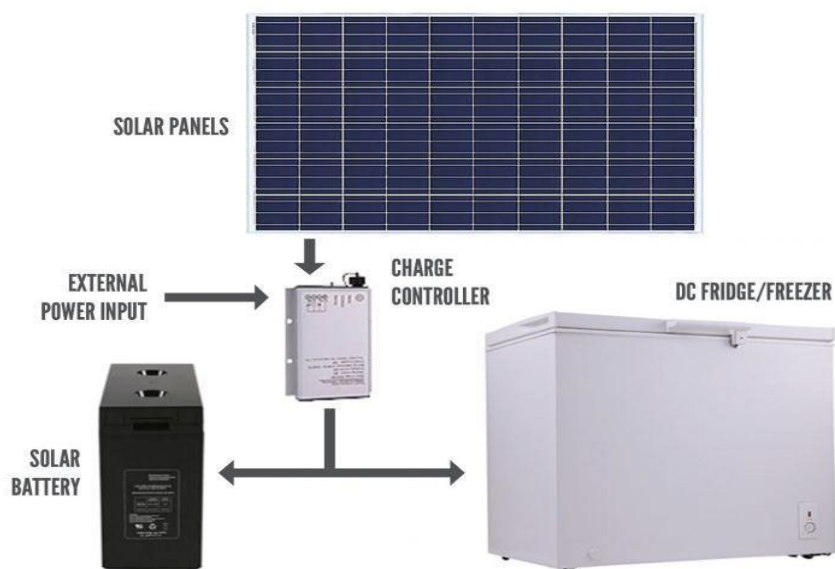
⁵⁴ ETCIO (2017). "How Promethean Power Systems is revitalizing the dairy farming industry". Source: <https://cio.economicstimes.indiatimes.com/news/corporate-news/how-promethean-power-systems-is-revitalizing-dairy-farming-industry/56908332>

SOLAR REFRIGERATOR

Solar refrigerators are ordinary refrigerators that are powered by the energy directly provided by sunlight. Rather than a stationary temperature-controlled room, solar refrigerators are much smaller in size and holding capacity, similar to ordinary refrigerators. Traditionally, a combination of solar panels and lead-acid batteries is used to store generated energy for periods when sunlight is unavailable, such as during cloudy days or at night.⁵⁵ They are commonly used in areas where inhabitants are either totally unconnected to the grid or receive little to no power supply from the grid. Temperatures can range from 0°C to +10°C and would be highly beneficial for livestock farmers and markets.

There is a solar refrigerator unit currently in development by TreeSeaMals Ltd intended to provide up to 1600 kg (1.6 metric tons) per day of cold storage for farmers using the combined energy generation of an assembly of solar panels.⁵⁶ This technology can be highly cost intensive due to the relatively short life span of the batteries, which necessitates frequent replacement. It can be very difficult to obtain the batteries, which can make it unattractive as a long-term solution.⁵⁷

Figure 4: Solar Refrigerator Diagram⁵⁸



⁵⁵ United Nations International Children’s Emergency Fund (2014). “Battery Powered Solar Refrigerators and Freezers”. Source: <http://iaphl.org/wp-content/uploads/2018/05/Battery-Powered-Solar-Refrigerators-and-Freezers-Copy.pdf>

⁵⁶ Tree_Sea.mals. Source: <https://www.treeseamals.org>

⁵⁷ World Health Organization (WHO) (2015). “Introducing Solar-Powered Vaccine Refrigerator and Freezer Systems: A Guide for Managers in National Immunization Programs”. Source: https://apps.who.int/iris/bitstream/handle/10665/195778/9789241509862_eng.pdf?sequence=1

⁵⁸ Green NRG Co (undated). Solar Fridge & Freezer. Source: <https://greennrgco.com/solar-fridge-freezer/>

REFRIGERATED TRAILER

Refrigerated trailer also known as “reefer” is a refrigerated container attached to a semi-truck and used to transport perishables and other temperature-sensitive goods. Cooling a reefer can be achieved through diesel powered generators or solar energy systems.

The major components of reefer containers include the compressor (takes in gaseous refrigerant for compression), the condenser (takes the output liquid from the compressor) and the evaporator (inside where the cool refrigerant assumes a gaseous state again).

The system continuously removes heat and maintains a constant low temperature within the unit to preserve the food. Reefer capacity varies, some can hold up to 50 gallons of diesel, for the diesel fueled type, an equivalent of 4 to 5 days driving. More so, it is known for its ability to carry goods at a constant temperature of as low as -20 degrees °C.⁵⁹ It can be used to transport meat, fish, fruits, vegetables, confectionaries, and other food products.

Alyx Limited in Nigeria provides solar refrigerated trailers to help farmers transport produce from their farms to the markets. Their units can be used for pre-cooling perishable foodstuff of up to 5000kg (5 metric tons) and can be rented to farmers during harvest for pre-cooling, storage, and transport, thereby maintaining continuous cold chain transportation for onward movement to markets. However, if these vehicles are not fitted with a temperature monitoring system and are not operated by properly trained workers, there is a significant risk of spoilage in transit.

SOLAR ICE MAKER

A solar ice maker can be part of a solar freezer or a stand-alone appliance, which uses photovoltaic cells to generate electricity, which is then used to make the ice. The blocks of ice are created during daylight hours and kept at 0°C within the ice maker at night using battery power. Like other methods of cold storage, ice reduces the temperature of the fish to 0°C by direct application. Furthermore, the large cooling capacity of ice, with a latent heat fusion of 80 kcal/kg, provides for the chilling of large quantities of fish with much smaller quantities of ice.⁶⁰ This presents an efficient and cost-effective method of preserving fish, especially when used in conjunction with insulated containers that keep the ice solid for longer. This is amplified by the fairly high availability of freshwater in Nigeria, which is the most ideal source of ice, as opposed to ocean saltwater.

The thermal capacity of the solar ice makers allows for the use of ice as energy storage, which preserves food for multiple days at a time in the absence of sunlight. This makes it ideal in situations where there is erratic power supply, or where energy costs are too high. Furthermore, the compact size and portability of these machines allows for them to be used anywhere to chill a wide variety of foodstuffs and drinks.



An Alyx Refrigerated Trailer Funded by the Rockefeller Foundation, USAID, and GAIN

⁵⁹ Refrigerated Truck Bodies (2021). “How does a Refrigerated Truck Work?”. Source: <https://rtbodies.com.au/how-does-a-refrigerated-truck-work/>

⁶⁰ Food and Agricultural Organization of the United Nations (FAO) (1995). “Quality and quality changes in fresh fish”. Source: <http://www.fao.org/3/v7180e/v7180e00.htm#Contents>

Table 4: Cold Storage Systems and Storing Capacity

System	Food Suitability	Capacity (Liters)	Temperature	Energy Requirement
Cold Room	Tubers, Fruits, and Vegetables	13,28	5°C	5.7 kWh
Cold Room ⁶¹	Milk, Tubers, Fruits, and Vegetables	9,714 – 382,481	5°C and below	8kWh - 120kWh
Blast Freezer ⁵⁸	Meat, Fish, Vegetables	150 – 1500	-18°C and below*	10kWh - 64kWh
Conventional Milk Chiller, Rapid Milk Chiller, and Rapid Milk Chiller Premium ⁶²	Milk	500 – 2000	4°C	5kWh - 12.4kWh
Solar freezer ⁶³	Meat, Fish, **Fruits, and Vegetables	118 - 218	-18°C and below*	20kWh - 80kWh
Standard refrigerator	Milk, Tubers, Fruits, and Vegetables	100 - 250	Below 4°C	1 - 2 kWh**
Solar refrigerator ⁶⁴	Milk, Tubers, Fruits, and Vegetables	1,600	Below 4°C	2.5kWh - 8.4kWh
Refrigerated Trailer ⁶⁵	Milk, Tubers, Fruits, and Vegetables	Varies widely depending on size and purpose	+12°C to -25°C ⁶⁶	5.5kWh - 80 kWh
Solar Ice maker ⁶⁷	Meat, Fish	160	0°C and below	600 Watts

*Standard temperature range of freezers

** Frozen fruit and vegetable

OBSTACLES TO COLD STORAGE ACCESS IN NIGERIA

Despite the clear need for cold chain products and services across Nigeria, the supply of these technologies remains limited compared to the number of farmers and agribusinesses who remain without access to cold storage. This gap is the result of myriad economic, social, geographical, infrastructure, and logistical challenges. Obstacles to increased cold chain infrastructure in Nigeria include:

⁶¹ De Koolar Nigeria Limited Price List. Source: <https://www.dekoolar.com/price-list/>

⁶² Promethean Power Systems' Conventional Milk Chiller. Source: <https://coolectrica.com/products/conventional-milk-chiller/>

⁶³ Jumia (2020). Source: <https://www.jumia.com.ng/mlp-solar-freezer/>

⁶⁴ Engineering for Change (2020). Tree.Sea_mals. Source: <https://www.engineeringforchange.org/solutions/product/solar-powered-communal-refrigeration/>

⁶⁵ eNow Rayfrigeration™ Trailer Systems (2020): “Zero-Emission All-Electric Reefers”. Source: <https://www.enowenergy.com/copy-1-intro-to-enow-rayfrigeration-trailer-systems/>

⁶⁶ IndiaMART. Mobile Refrigerated Van. Source: <https://www.indiamart.com/proddetail/mobile-refrigerated-van-17416010355.html>

⁶⁷ Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2020) Solar Ice Maker. Source: https://energypedia.info/images/9/9b/Techsheat_A3_solar_ice_maker_V3.0.pdf

- **Lack of awareness (demand side):** In some cases, in rural communities, smallholder farmers and fishermen are unaware of cold storage systems entirely and their potential to reduce post-harvest losses and preserve food produce. In cases where farmers are aware of technologies, there is still a knowledge gap of how to purchase the appropriate cold storage facilities and access electricity required to power them.⁶⁴
- **Lack of awareness on the part of banks and other lenders:** Financial institutions have limited information about solar-powered cold storage technology and the business potential (i.e. return on investment, payback period).⁶⁸ Consequently, they are quite reluctant to lend to businesses seeking to raise the needed capital to acquire/construct and distribute the equipment to target areas ripe with opportunity. This has the effect of depriving communities in need of this technology not only access to it, but also from reaping the rewards that come with it.
- **Poor access to finance:** Potential cold storage customers (e.g., farmers and agribusinesses) often lack access to credit facilities required to purchase the systems. This lack of credit is prevalent in general but particularly in the case of cold storage where the absence of a business case makes banks reluctant to extend financial products.⁶⁵
- **Inconsistent energy supply:** Erratic power nationwide hinders the introduction, uptake, and effectiveness of conventional cold storage technologies, especially in communities that are completely unconnected to the grid. Many cold chain service providers must depend on diesel-powered generators, which are commonplace across the country, to ensure that they are able to provide round-the-clock service to their customers. The reliance on diesel leads to higher operational costs due to the high cost of diesel in Nigeria. This reduces the bottom line of farmers and businesses alike.
- **High energy demand:** Nigeria's hot climate, particularly in the northern regions of the country where most agricultural activities occur, is highly conducive to the growth of bacterial organisms that spoil food. These organisms thrive within the temperature range of 40°F - 140°F (4.4°C - 60°C). The current average monthly temperature for Nigeria ranges from 24°C (December, January) to 30°C (April).⁶⁹ The average monthly temperature in Nigeria is expected to rise to 30°C between 2020 and 2039 in the absence of significant climate change mitigation. This will lead to a significant increase in the already high energy demand required to meet cooling needs.⁷⁰
- **High capital costs of cold storage technologies:** The high costs of transport and energy infrastructure required to provide cold storage technologies to rural users are a deterrence to inflows of investment because the cold storage units would have to be built from scratch in the area of deployment. Suppliers of cold storage units usually assemble the equipment and facilities at the base of operations before deploying the finished product to the place or community it was purchased for. However, if this is extremely difficult to do, they would be forced to transport the individual components to the location and assemble it there. This significantly increases their costs, which leads to a reduction in the amount of profit generated from the sale.

⁶⁸ Global Off-Grid Lighting Association (GOGLA) (2021). "Decentralized Solar Refrigeration: Opportunities in the Livelihood Appliances Market in India". Source: <https://www.gogla.org/resources/decentralised-solar-refrigeration-opportunities-in-the-livelihood-appliances-market-in>

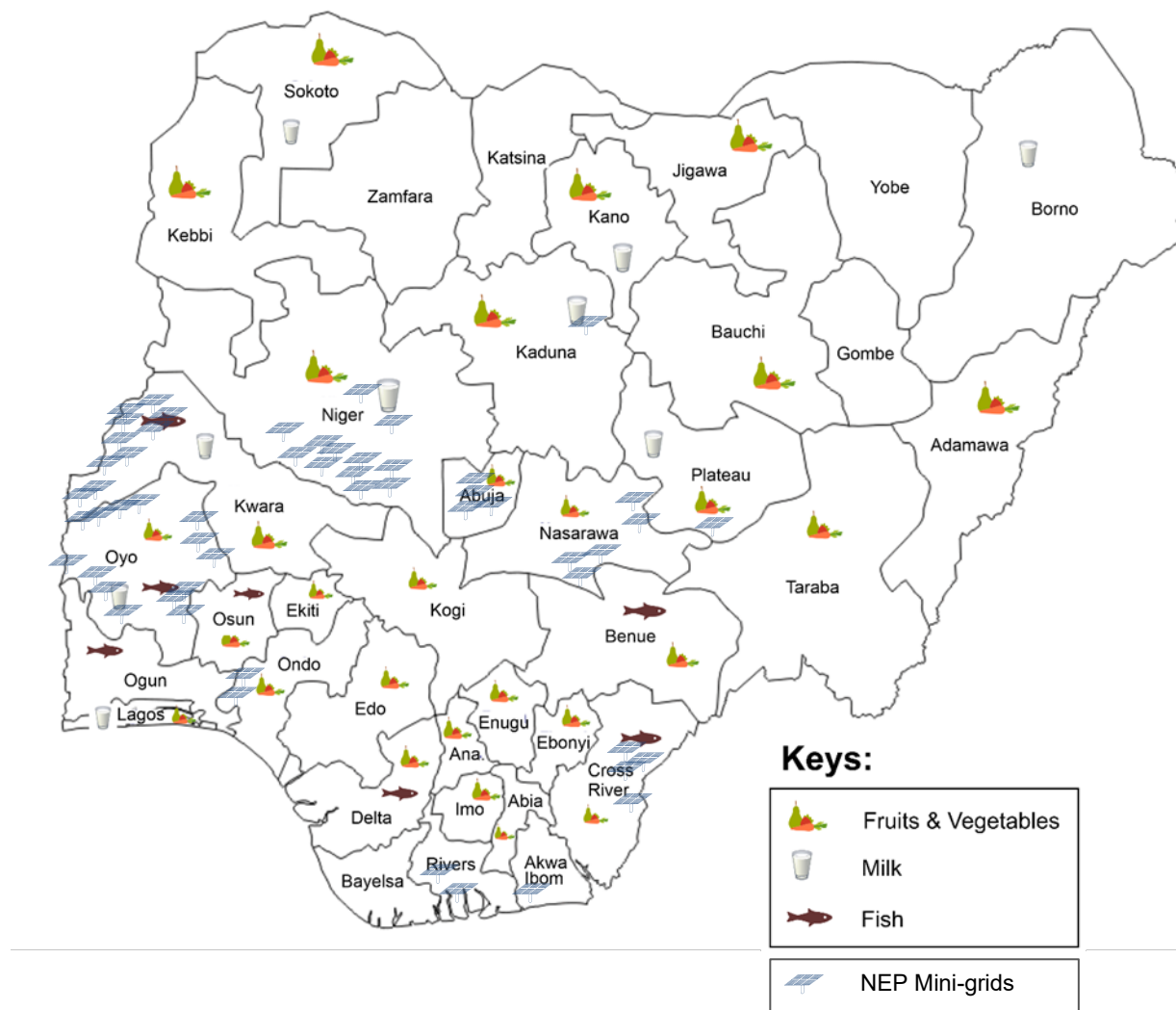
⁶⁹ Climate Change Knowledge Portal. "Nigeria" Source: <https://climateknowledgeportal.worldbank.org/country/nigeria/climate-data-historical>

⁷⁰ International Institute for Applied Systems Analysis (2019). "More energy needed to cope with climate change". Source: <https://www.sciencedaily.com/releases/2019/06/190624111437.htm>

OFF-GRID SOLAR COLD STORAGE DEPLOYMENT

Leveraging existing mini-grids to power cold storage systems across states in Nigeria will require strategic location pairing and partnerships with SPCSS service providers across the country (Figure 6). The mini-grid site is ideally located within the target customers' catchment area and in cases where existing mini-grids pairing is not economically viable due to the additional cost of extending power distribution lines to catchment areas, standalone systems can be employed.

Figure 5: Potential Demand for SPCSS, by State, Commodity



Cold storage systems and storage capacity varies, depending on the food commodity to be preserved (Table 4). According to food safety guidance for power outages, refrigerators and freezers can continue to store contents for up to 4 and 48 hours respectively if the doors stay closed. There is currently no open-source literature documenting the approximate number of cold storage systems powered by mini-grids or standalone solar systems in Nigeria.

Smallholder farmers, agribusinesses, logistic companies, and fishermen depend on cold storage systems to preserve highly perishable income-generating produce. In turn, cold storage systems suppliers and service

providers provide cold storage equipment including cold rooms, industrial blast freezers, milk chillers, communal refrigerators, mobile refrigerated trailers, and ice makers, to these target customers.

There are different target customers who would benefit greatly from SPCSS deployment across states in Nigeria. Cold storage systems and service providers target a range of customers including dairy farmers, FFV farmers, fishermen, agribusinesses, and aggregators.

- **FFV Farmers:** FFV farmers are usually smallholder farmers that own small plots of land, usually less than one hectare. They own comparatively few production-enhancing assets for farming, relying mainly on the use of crude technologies. Due to the lack of availability of financing, smallholder farmers cultivate labor-intensive, low-value crops which limit their income and can cause them to easily slide into greater poverty.
- **Dairy Farmers:** Dairy farmers usually operate on a small-scale. Free ranging dairy cattle are fed and watered whenever the opportunity to do so arises, with limited access to improved pastures or supplemented feed to maintain consistent nutrient intake.⁷¹
- **Fishermen:** Fishermen also operate on a small-scale. Refrigeration or freezing can be used to preserve wild-caught fish, and are especially useful for the preservation of shellfish, which is typically harvested much earlier in the value chain and thus spoils earlier. Freezing allows fish to be sold to markets farther beyond the community in which they are produced.
- **Agribusinesses:** Agribusinesses own multiple, large farmlands (usually > 20 hectares) leveraging productivity enhancing technologies such as irrigation systems, fertigation systems, and tractors to increase productivity and output. Agribusinesses spend significant funds on production inputs which results in issues around post-harvest losses as less investment is made in the purchase of cold storage technologies.⁷²
- **Aggregators:** Aggregators collect food produce from multiple locations in large quantities, store, and transport to the market for sale. They leverage cold storage solutions to reduce the risk of spoilage during storage and transportation. The aggregators are an ideal target customer for cold storage technologies given the large number of produce and dairy they store and transport.⁶⁸ Farmer associations can act as aggregators to their members, gathering the harvested crops from their members (farmers) and transporting them to the market for sale.
- **Supermarkets:** Supermarkets are where perishable goods such as meat, fish and milk are retailed to the general public, who require these goods. The capacity of the cold storage system required within supermarkets typically varies depending on the amount of perishable goods supplied to supermarkets.
- **Logistic companies:** All the target customers, in some way, need to transport their highly perishable produce from one point to another. The supermarkets need to transport the food from the farm or processing center, the aggregators need to transport the food from multiple locations and in large quantities. To effectively transport the produced food without spoilage or loss, cold storage equipped logistics companies are necessary. Logistics companies require refrigerated transport vehicles that will foster the efficient distribution of highly perishable produce.

⁷¹ Food and Agricultural Organization of the United Nations (2018). "Livestock production systems spotlight: Nigeria dairy cattle and poultry sectors". Source: <http://www.fao.org/3/CA1790EN/ca1790en.pdf>

⁷² United States Agency for International Development (USAID) (2019). "Technology Case Study: Clean Energy Cold Storage". Powering Agriculture: An Energy Grand Challenge for Development.

BUSINESS MODELS FOR SPCSS DEPLOYMENT

There are five potential business models for deploying SPCSS in Nigeria: commercial partner model, developer-owned model, non-commercial entity model, and SPCSS provider-owned model. Each requires a unique set of stakeholders and roles and responsibilities and has both advantages and disadvantages to deployment.

Non-commercial Entity Model. The non-commercial entity model requires the mini-grid developer to work with an NGO or other non-commercial entity, such as the government, to set up and operate cold storage systems to serve the needs of the target customers. Under this model, non-commercial entities can sponsor the upfront capital expenditure, system installation, system operations, or any combination of these. The non-commercial entity may also sponsor upfront or installation costs, but still seek payment from target customers to pay back the investment. There are several NGOs and local organizations operating in the rural communities across states in Nigeria and working closely with community members on development projects. Possessing knowledge of the target communities and their needs, they are well placed to assist mini-grid developers in gathering reliable data for business case studies and social inclusion strategy development. For this type of model to succeed, boundaries must be clearly established with each actor having well-defined roles and expectations.

Table 5: Advantages and Disadvantages of Non-commercial Entity Model

Advantages	Disadvantages
<ul style="list-style-type: none"> Partnership with the government can increase project legitimacy and circumvents potential bureaucratic delays that increase the risk of project delay. 	<ul style="list-style-type: none"> Increased risk of non-payment by government or unsustainable donor development programs. Commercial experience of the government partner may be limited which could result in operational challenges.

Commercial Partner Model. This model is employed when cold storage is not easily accessible on demand within target communities where a mini-grid exists. In this model, a partnership is established between the mini-grid developer and a cold storage provider to bring cold storage systems such as a milk-chiller, cold room, and ice-maker to the target community.

For this type of model to flourish, the mini-grid must be capable of generating sufficient power required by the cold storage system. The cold storage provider must also be willing to integrate their system into the mini-grid and negotiate a viable tariff based on fees charged to customers for cold storage. This model also requires either the mini-grid developer or the cold storage solution provider to assess the cold storage needs of the community, determine willingness to pay for these services, and provide a solution that is aligned to both those cold storage needs and the customer price point.

Table 6: Advantages and Disadvantages of Commercial Partner Model

Advantages	Disadvantages
<ul style="list-style-type: none"> Increased energy demand for the mini-grid developer. No community-led investment required. 	<ul style="list-style-type: none"> The mini-grid developer may have limited insight into the cold storage activities of the customer base, which makes accurate projections of electricity demand more difficult. Furthermore, this demand may evolve or increase with the presence of a cold storage system.

- The mini-grid developer may require equipment specialist expertise which may incur additional expenses.
- If the commercial partner meets the cooling needs of the entire community, local small-scale cold storage businesses may be priced out of the marketplace due to an inability to compete, particularly if travel costs are involved and higher for other local small-scale cold storage businesses.

Developer-owned Model. In a developer-owned model, the mini-grid developer is also the provider of the cold storage system. Both the mini-grid utility and the cold storage system are owned and operated by the same party. This model is used to drive the productive use of energy by the mini-grid developer in a target community with cold storage needs.

Table 7: Advantages and Disadvantages of Developer-owned Model

Advantages	Disadvantages
<ul style="list-style-type: none"> • Increased energy demand for the mini-grid developer. • No community-led investment required. • An additional stream of revenue for the mini-grid developer while also giving the mini-grid developer full control over their customer base. 	<ul style="list-style-type: none"> • Increased financial burden associated with the procurement of cold storage system(s) if borne by the mini-grid developer. • The mini-grid developer may require equipment specialist expertise which incurs additional expenses. • If the commercial partner meets the cooling needs of the entire community, Local small-scale cold storage businesses may be priced out of the marketplace due to an inability to compete, particularly if travel costs are involved and higher for other local small-scale cold storage businesses.

Shared Community-owned Model. In a shared community model, members of the community form a group or association and purchase a cold storage system because of its benefits. The mini-grid developer works with the community, providing technical support such as recommendations on equipment compatibility based on energy needs. The community owns the cold storage system in this model but requires funding through grants, loans, and community contributions/savings.

Table 8: Advantages and Disadvantages of Shared Community-owned Model

Advantages	Disadvantages
<ul style="list-style-type: none"> • Increased usage of the cold storage system due to the trust fostered by internal ownership of the cold storage system. • Ownership of the cold storage system increases value and generates revenue for the community. 	<ul style="list-style-type: none"> • Increased financial risk for the community because of commitment to repaying loans and ongoing operational expenses. • The mini-grid developer may require equipment specialist expertise which may incur additional expenses.

- An additional stream of revenue for the mini-grid developer from the increased demand of the cold storage system.

SPCSS Provider-owned Model. In this model, the SPCSS provider owns, constructs, and operates the SPCSS. This model requires a facilitator to go into the rural off-grid communities to increase awareness among target customers on the benefits of SPCSS for food preservation. As mentioned earlier, the mini-grid developer can also be an SPCSS provider under the developer-owned model. Equity cum subsidy, rental, pay-as-you-store (PAYS) and ice-as-a-service (IAAS) are all examples of the repayment arrangements of the SPCSS provider-owned model.

Table 9: Advantages and Disadvantages of SPCSS Provider-owned Model

Advantages	Disadvantages
<ul style="list-style-type: none"> • This is the quickest to deploy and implement as the SPCSS provider retains sole custody of operations. Therefore, the process is not slowed by negotiations or disputes with third parties. • The provider has full control over their customer base. 	<ul style="list-style-type: none"> • In lieu of proactive measures by the SPCSS provider, there is a lack of community involvement and participation in decision making related to the system, weakening the community’s sense of ownership and limiting the extent to which system management decisions reflect community and target customer needs. • The risk of the business venture is borne by the SPCSS provider who is solely responsible for raising capital. With no partners to share the financial burden, the provider could encounter significant issues raising capital, maintaining healthy profit margins, and could face insurmountable financial challenges should the venture fail.

PAYMENT OPTIONS FOR ACCESSING SPCSS

The options to access cold storage could be through either a full or partial ownership or pay-per-use, if made available. These are explained as below.

- **Equity cum subsidy.** Suppliers provide SPCSS at discounted rates to the target customers within a community, of which a share of the deployment cost is borne by the government/donors as capital subsidy.
- **Pay-as-you-store (PAYS).** Pay-as-you-store (PAYS) is a financing approach that allows target customers to pay a daily flat fee for food they store in the cold storage. Alternative names for the PAYS approach include pay-as-you-chill and pay-as-you-freeze or cooling-as-a-service. This type of credit system removes the initial financial barrier to solar energy access by allowing consumers to make a series of modest payments to purchase time units for using the SPCSS instead of paying upfront for the entire system. In Nigeria, one of the largest solar cold storage providers operates

via the PAYS repayment model. SPCSS providers adopting a “pay-per-use” approach are reported in Appendix A.

- **Rental.** Through renting, the supplier owns, maintains, and rents the SPCSS to interested target customers (individual or group). SPCSS such as milk chillers and mobile refrigerated solar trailers are well suited for this type of arrangement. Alyx Ltd, Nigeria operates via this approach whereby farmers rent its mobile solar-powered refrigeration truck during harvest for pre-cooling, storage, and transport.
- **Lease-To-Own (LTO).** The Lease-To-Own (LTO) model is intended to make chilling and freezing services more affordable by allowing the customers to pay for the units in small installments over an agreed period of time. Depending on the specific arrangement with the provider, the customer can either acquire or purchase the unit upon completion of payment at the end of the lease tenure. Eja Ice is currently developing LTO offerings to both group and individual fish retailers.⁷³
- **Ice-as-a-service (IAAS).** Under this service, the SPCSS provider makes ice blocks and sells for a fee to target customers.

⁷³ UpLink (2021). “Eja-Ice: Scaling Cold Chain Access for Women led Fish Retailers & other SMEs”. Source: <https://uplink.weforum.org/uplink/s/uplink-contribution/a012o00001pTYJ2AAO/ejaice-scaling-cold-chain-access-for-women-led-fish-retailers-other-smes>

Table 10: Advantages and Disadvantages of SPCSS Payment Options

Model	Advantages	Disadvantages
<i>Equity Cum Subsidy</i>	<ul style="list-style-type: none"> Subsidized capital cost encourages target customers patronage of SPCSS. 	<ul style="list-style-type: none"> Availability of subsidized capital is temporary and target customers may not be able to continue payment at unsubsidized rate.
<i>PAYS</i>	<ul style="list-style-type: none"> Ease of payment for target customers with limited finances. 	<ul style="list-style-type: none"> Poses a financial risk to the supplier who bears the cost of installation, maintenance, and repairs.
<i>Rental</i>	<ul style="list-style-type: none"> Eliminates the burden of purchasing SPCSS, farmers make use of the system based on their income/ability to rent. Farmers pay for the system only when needed. 	<ul style="list-style-type: none"> Subject to supplier rates which may increase when demand is high and limiting farmers ability to pay.
<i>LTO</i>	<ul style="list-style-type: none"> Allows customers to test SPCSS units before making the decision to purchase.⁷⁴ 	<ul style="list-style-type: none"> Lease payment systems such as mobile money are still emerging in Nigeria limiting adoption of LTO
<i>IAAS</i>	<ul style="list-style-type: none"> Quick implementation Suitable payment options for customers with limited finances. High utilization factor compared to other cooling methods. 	<ul style="list-style-type: none"> Higher energy demand required for freezing.

SUSTAINABILITY OF SPCSS DEPLOYMENT

Sustainable development is development that meets the economic, social, and environmental needs of the present without compromising the ability of future generations to meet their own needs.⁷⁵ Hence the sustainability of SPCSS deployment is highly dependent on these factors.

Economic Sustainability. The economic sustainability of powering cold storage systems with solar energy systems is determined by capital costs, expected additional revenues from solar cold storage systems, and costs of alternative cold storage systems. SPCSS underlying economics are influenced by the volume of cold storage, cooling temperature, cooling duration, access to finance, and access to markets.

- Volume of Cold Storage:** Larger capacity of cold storage solutions can accommodate more goods and cater to a larger customer base, giving rise to lower per-unit costs. This is ideal for service providers who offer a pay-as-you-go service. Initial capital investments are still greater with larger capacity of cold storage systems, requiring more solar panels and batteries. Smallholder customers may not be able to purchase larger capacity of cold storage equipment individually, due to high capital cost, but they can do so jointly through cooperatives and joint agreements.
- Cooling Temperature:** The lower the cooling temperature that is required, the higher the energy demand and therefore associated energy cost. SPCSS requiring lower cooling temperature, will require more electricity i.e., more solar panels and batteries which leads to increased capital cost.
- Access to Finance:** As shown in Appendix A, cold storage systems are expensive and require financial aid (usually administered through grants, equity, or loan). Lack of demonstrable bankable business cases means poor access to finance for enterprises. Solar cold storage companies must

⁷⁴ CRS Cold Storage (2018). "The Benefits of Cold Storage Lease to Buy". Source: <https://www.crsoldstorage.co.uk/news/lease-to-buy.html>

⁷⁵ EUR-Lex (2009). Glossary if summaries. Source: https://eur-lex.europa.eu/summary/glossary/sustainable_development.html

develop and demonstrate bankable business cases and proof-of-concept to attract commercial financing.⁷⁶

- **Access to Market:** In many developing countries, smallholder farmers and fishermen generally lack access to market information about crop and dairy prices, and the benefits of cold storage for profit-making. This emphasizes the need for a facilitator who can facilitate market-linkage and extension programs that promote awareness on the benefits of the SPCSS to support market expansion.

Social Sustainability. Social sustainability can be defined as identifying and managing both positive and negative impacts of systems, processes, organizations, and activities on people and social life.⁷⁷ Public opinion and acceptance are important for the successful introduction and adaptation of alternative technologies into society. These factors are influenced by certain determinants such as risks and benefits of the technology, estimated costs, and gender and social equity.⁷⁸

Below are the determinants of social sustainability associated with solar-powered cold storage deployment.

- **Technology Awareness:** The absence of information and knowledge about alternative cold storage solutions serves as a barrier to discovering solutions that are cost effective. There is a need for awareness campaigns, technology demonstration and training exercises to spread awareness among farmers and other stakeholders and enable them to make informed decisions. For this purpose, a facilitator is necessary to champion awareness campaigns leveraging local knowledge networks to spread information and increase acceptance of solar-powered cold storage solutions among target customers.⁷⁹
- **System Theft:** Solar panels consist of almost half of the total system costs and are vulnerable to theft and physical damage. Several cases of solar panel thefts have been recorded in developing countries such as India, Zimbabwe, South Africa, and Mali. Safety measures such as fencing, security fasteners, anti-theft bolts, alarms, and system monitoring tools can be adopted to secure solar panels against risks of theft, however, these safety measures are cost incurring and increase capital costs.⁷³

Gender-Related Constraints to SPCSS Deployment. Across the cold storage value chain, men and women perform different tasks, having different skills and decision-making roles. According to the Federal Ministry of Agriculture & Rural Development (FMARD), women account for 75% of the farming population in Nigeria (i.e., smallholder farmers), primarily engaging in farming activities such as irrigation, weeding, harvesting, on-farm processing, and selling of farm produce. However, women farmers are often disadvantaged and have fewer educational, advancement, or other income-generating opportunities than their male counterparts, despite producing over 80% of food consumed in the country.^{80,81}

⁷⁶ Agrawal, S. & Jain, A. (2018). "Sustainable deployment of solar irrigation pumps: Key determinants and strategies." Wiley Interdisciplinary Reviews: Energy and Environment.

⁷⁷ Balaman, S. Y. (2019). Sustainability Issues in Biomass-Based Production Chains. In Decision-Making for Biomass-Based Production Chains (pp. 77–112). Elsevier. Source: <https://doi.org/10.1016/b978-0-12-814278-3.00004-2>

⁷⁸ Huijts, N. M. A.; Molin, E. J. E.; Steg, L. (2012). "Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework". Renewable and Sustainable Energy Reviews, 16(1), 525 - 531. Source: <https://www.sciencedirect.com/science/article/abs/pii/S136403211100428X?via%3Dihub>

⁷⁹ Food and Agricultural Organization of the United Nations (FAO) (2018). Small Family Farms Country Factsheet. Source: <http://www.fao.org/3/i9930en/I9930EN.pdf>

⁸⁰ Sahel (2016). Sahel Newsletter Volume 7. Source: <http://sahelcp.com/wp-content/uploads/2016/12/Sahel-Newsletter-Volume-7.pdf>

⁸¹ Food and Agricultural Organization of the United Nations (2003). Gender – Key to Sustainability and Food Security. Plan of Action for Women in Development.

Women dairy farmers tend to sell surplus milk in local markets themselves or to local traders. This process can be time-consuming and expensive after accounting for transportation costs, especially when traders do not arrive to offtake the milk, it is up to these women to find a buyer themselves.⁸²

SPCSS offers business investment opportunities for women who are entrepreneurs, women farmers, and fishermen. However, hard-wired energy systems such as cold storage systems, tend to target male users giving less attention to increasing women's access.⁸³ Additional challenges facing women in the agriculture sector are detailed below.

Inability to own land: In many parts of Nigeria, the traditional laws and customary practices strictly prohibit women from owning land. The ownership rights to land are usually conferred exclusively upon men or male-controlled kinship groups, and women only have the right to access the land through their connection to a male relative, often being her father or husband.⁸⁴ According to the 2012 "Gender in Nigeria" report published by the British Council, men are five times more likely than women to own land on average, and as much as 13 times more likely than women to own land in the North-East region.⁸⁵ Consequently, women are unable to access the much-needed loans from banks and other financing institutions as they cannot provide land as collateral.

Limited financial capacity: Although women dominate the agricultural sector in Nigeria, they tend to be engaged in unpaid labor.⁸⁶ This is a result of working on family-owned and male-controlled farmlands, which does not grant them the authority to determine how any income generated from the land is used. Furthermore, the majority of these women, especially those who live in rural areas, are from low-income backgrounds and have little to no formal education.⁸⁷ Subsequently, their earning potential is severely limited, and they are unable to raise sufficient funds from farm produce or other ventures to buy, rent or otherwise gain access to SPCSS.

Environmental Sustainability. The environmental sustainability of solar cold storage solutions is largely understood in terms of its influence on the surrounding environment, especially in its contribution to electronic waste and climate change. Informed selection and adequate maintenance measures for each component of SPCSS as well as proper disposal at its end of useful life are essential to its environmental sustainability. End-of-life management is important for components such as solar panels, controllers, and inverters, which are categorized as e-waste, and their improper disposal could negatively affect the environment. As the spread of SPCSS increases in the future, proper disposal at the end of useful life will become a concern for environmental sustainability.⁷²

Refrigerant selection is an important step towards ensuring environmental safety and sustainability of SPCSS. Cold storage systems directly contribute to climate change through the leakage of refrigerants into the atmosphere. A refrigerant is a substance used as a heat carrier in cold storage systems that eliminates heat from an area through absorption and discharges it elsewhere, providing cool air in the

⁸² Sahel Consulting (2019). Nigerian Dairy Development Program Documentary.

⁸³ Edomah, N.; Foulds, C.; and Malo, I. (2021). Energy Access and Gender in Nigeria: Policy Brief. Cambridge: Global Sustainability Institute.

⁸⁴ Africa Renewal (2012). "Women struggle to secure land rights". African News and Analysis from the United Nations. Source: <https://www.un.org/africarenewal/magazine/special-edition-women-2012/women-struggle-secure-land-rights>

⁸⁵ British Council (2012). "Gender in Nigeria Report 2012: Improving the Lives of Girls and Women in Nigeria". Source: <https://www.britishcouncil.org/sites/default/files/british-council-gender-nigeria2012.pdf>

⁸⁶ African Development Bank (2015). "Economic Empowerment of African Women through Equitable Participation in Agricultural Value Chains". Source: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Economic_Empowerment_of_African_Women_through_Equitable_Participation_in_Agricultural_Value_Chains.pdf

⁸⁷ Girardeau, H.; Aharonian, A.; Zoghbi, E.; Uwamaliya, A.; Mehic, S.; Dean, B.; Hartley, B.; Kent, S.; and Otarra, M. (2021). "Cooling for All and Gender: Towards Inclusive, Sustainable Cooling Solutions". Sustainable Energy for All (SEforAll). Source: <https://www.unwomen.org/en/news/in-focus/commission-on-the-status-of-women-2012/facts-and-figures>

process.⁸⁸ It can phase change from gas to liquid and back to gas during the refrigeration cycle.⁸⁹ Chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons (unreactive gaseous compounds of carbon with halogens such as bromine), and methyl are examples of refrigerants that are ozone-depleting substances (ODSs). These are compounds that deplete the ozone layer of the Earth's atmosphere when exposed to intense ultraviolet (UV) light in the stratosphere, resulting in the release of chlorine or bromine, which react with the ozone. Thus, these refrigerants have a high global warming potential (GWP), which indicates a capacity to absorb more infrared radiation over its lifetime in the atmosphere, thereby accelerating the rate of global warming.⁹⁰

The climate impact of cold storage equipment is determined by the direct and indirect effects of its use on the environment, with the direct effect being the GWP of the refrigerants used and the indirect effect accounting for the energy consumed during the operation of equipment over its lifetime. The extent of refrigerant leakage varies considerably between different cold storage equipment types and countries. Reliable data on refrigerant emissions in Nigeria is scarce but available data from GIZ indicate that refrigerant emissions are twice as high in developing countries than in industrialized countries.⁹¹ Through the efforts of the Montreal Protocol, which was specifically designed to protect the ozone layer by phasing out the production and consumption of substances contributing to ozone depletion, countries have banned the use of CFCs and HCFCs. Currently, Nigeria is in the process of phasing out HCFCs, prompted by the rapid increase in the use of HFCs as a replacement of CFCs.⁹²

Alternative solutions include the replacement of HCFCs and HFCs based systems and materials with low global warming potential (GWP) refrigerant. For example, in the refrigeration and air conditioning systems, refrigerant alternatives may include: HFOs, blended HFCs, ammonia, and CO₂. Also, refrigerant efficient systems can be adopted to reduce the amount of refrigerant usage. Furthermore, scheduled maintenance practices can be adopted to prevent the leakage of refrigerants into the atmosphere.⁹³

⁸⁸ Dependable Heating & Air Conditioning (2019). The Different Types of Refrigerants Used in Air Conditioners. Source: <https://www.dependableair.com/blog/2019/august/the-different-types-of-refrigerants-used-in-air/>

⁸⁹ Kubba, S. (2016). "Impact of Energy and Atmosphere". In Kubba, Sam (ed.) LEED v4 Practices, Certification, and Accreditation Handbook, (Second Edition, pp. 409-518). Butterworth-Heinemann.

⁹⁰ Gillenwater, M. (2015). "What is a Global Warming Potential? Greenhouse Gas Management Institute." Source: <http://ghginstitute.org/2010/06/28/what-is-a-globalwarming-potential/>

⁹¹ Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) (2017). <http://www.green-cooling-initiative.org/technology/chillers/green-cooling-potential/>

⁹² The Guardian (2020). "FG commits to ozone depleting substance phase-out". Source: <https://guardian.ng/property/fg-commits-to-ozone-depleting-substance-phase-out/>

⁹³ International Finance Corporation (IFC) (2017). "EDGE Guidance Document for Refrigerant Selection to Reduce Climate Impact based on the Montreal Protocol". Source: https://edgebuildings.com/wp-content/uploads/2017/04/170403-RefrigerantSelection_EDGE_MontrealProtocol.pdf

FINANCING OPTIONS AND PARTNERSHIPS

In order to facilitate the effective deployment of cold storage solutions in Nigeria, it is crucial to ensure that adequate financing, sufficient training on SPCSS selection, use and maintenance, and affordable payment options are available and accessible. Any business model that accounts for these criteria possesses a strong likelihood of flourishing in the Nigerian market. Well-designed financing structures and partnerships that have a defined set of interactions and funding flows between actors can enable successful deployment of SPCSS. Two or more of the financing structures identified in this section can be combined and adopted to enable successful procurement of SPCSS. There is a great need for actors (i.e. institutions, cooperatives, developers, suppliers) to work together and where possible form partnerships. Some potential actors are also well-suited to play multiple roles.

The following are examples of key actors necessary for each financing structure discussed:

- **Target Customers:** Any of the target customers, previously mentioned, may acquire loans, or grant to invest in SPCSS. They will be responsible for loan repayment and maintenance of the system over its lifetime. Target customers include smallholder farmers and agricultural cooperatives.
- **Mini-grid Developer:** The mini-grid developer develops and deploys the mini-grid that provides the electricity necessary for powering SPCSS. Typically, the mini-grid developers acquire grants from government and donor agencies, as well as debt financing from Private Finance Institutions (PFI). Alternatively, capital from equity investors or developers' balance sheets, may be invested in SPCSS projects.
- **SPCSS Provider (Service):** The service provider offers cooling as a service to target customers. They require financial support and may acquire loans and grants to enable acquisition of cold storage equipment. Under the developer-owned model, the mini-grid developer also plays the role of a service provider. Alternatively, capital from equity investors or balance sheets, may be invested in the SPCSS provider's company.

DEBT FINANCING

In simple terms, debt financing is borrowing money up-front for a large expenditure that is repaid over time at a fee (interest). In the SPCSS context, loan recipients may include customers, cold storage providers, or mini-grid developers. Debt financing occurs when stakeholders take out a loan from financial institutions, such as commercial or micro-finance banks at the prescribed interest rate to fund the deployment of SPCSS.

Additional actors well-suited to fulfill key roles in this financing structure include:

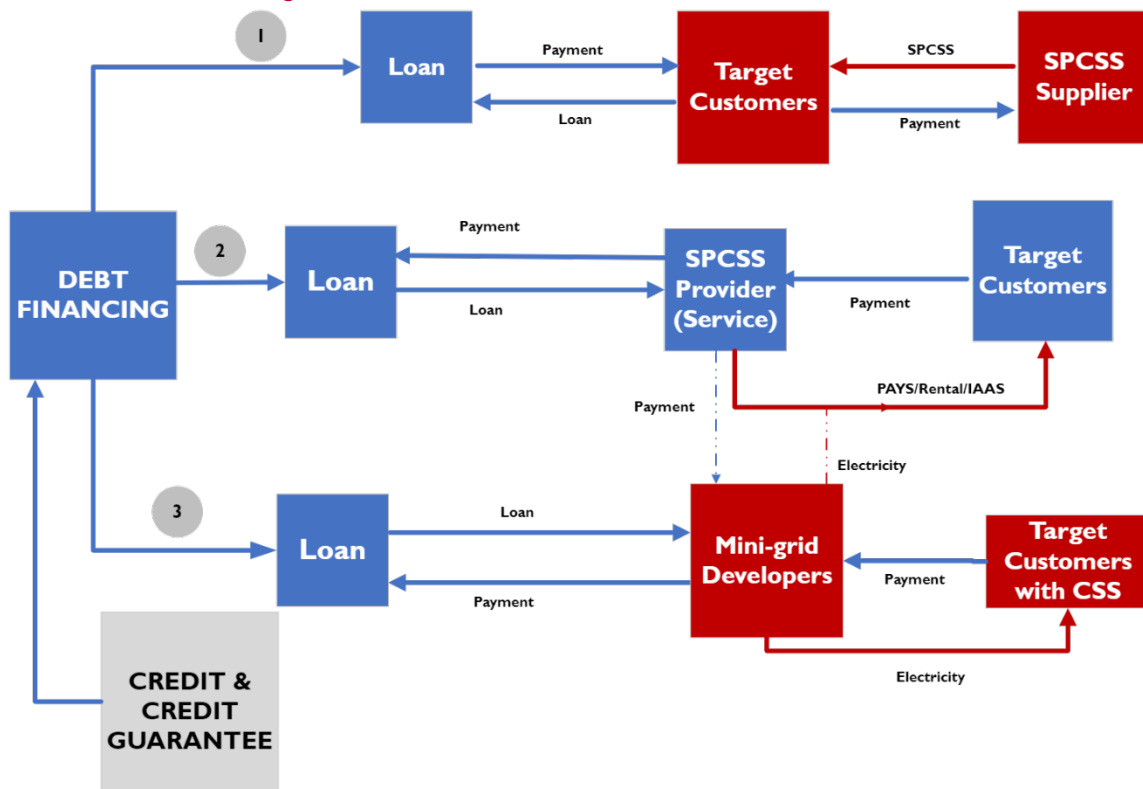
- **Credit and Credit Guarantee Facility:** The credit facility provides debt financing to Private Finance Institutions (PFIs) and is disbursed to mini-grid developers, SPCSS providers, or directly to smallholder farmers (dairy and FFV). The aim is to provide support while reducing risk because these PFIs have adequate structures to reclaim the loan when due. A credit guarantee facility, on the other hand, allows the government or other private sector organizations (potentially through donor agencies and international funding organizations) to provide guarantees to PFIs on loans, to reduce credit risk, thus enabling and encouraging PFIs to offer loans.
- **Private Finance Institutions (PFIs):** PFIs typically receive funding from the credit facility to fund mini-grid developers, standalone system providers, SPCSS suppliers or smallholder farmers. They usually have adequate channels in place to provide funds to these stakeholders and to make sure that it is used for the purpose for which it is sought. An example of a PFI is the Lift Above Poverty Organization Microfinance Bank (LAPO MFB), which offers agricultural loans between NGN 50,000 to NGN 500,000 (US\$121.95 to US\$1,219.51) to individual smallholder and farmer

cooperatives. The loan is low-interest without the requirement for collateral and has a flexible but short repayment period ranging between 12 months to 14 months. Another institution is the Grooming Center, which provides smallholder farmers with NGN 250,000 to NGN 750,000 (US\$609.76 to US\$1,829.27) at an interest rate of 14% to be repaid after 6 months. Further examples of PFIs are included in Appendix B.

Potential sources of debt financing can be obtained from government credit, credit guarantee schemes, and commercial bank loans. An example of a credit guarantee scheme is the Agricultural Credit Support Scheme (ACSS). The ACSS is an initiative of the Federal Government and the Central Bank of Nigeria (CBN) aimed at equipping farmers with the capacity to maximize the untapped potential of Nigeria’s agricultural sector.⁹⁴ Banks will initially grant loans to qualified applicants at 14% interest rate. Applicants who pay back their loan with the attached interest on time will enjoy an interest rate reduction of 6%, bringing the total amount of interest payable by farmers to 8%. Another example is the Commercial Agriculture Credit Scheme (CACCS), which provides complementary concessionary funding for existing programs such as the ACSS that target smallholder farmers.⁹⁵ Further examples of sources of debt financing are included in Appendix B.

There are no available schemes and loans in Nigeria specifically tailored to financing cold storage systems. Most of the schemes and loan options identified are for Agricultural purposes, which cold storage systems fall under.

Figure 6: SPCSS Debt Financing Structure



⁹⁴ Central Bank of Nigeria (2010). Agricultural Credit. Source: <https://www.cbn.gov.ng/devfin/acgsf.asp>

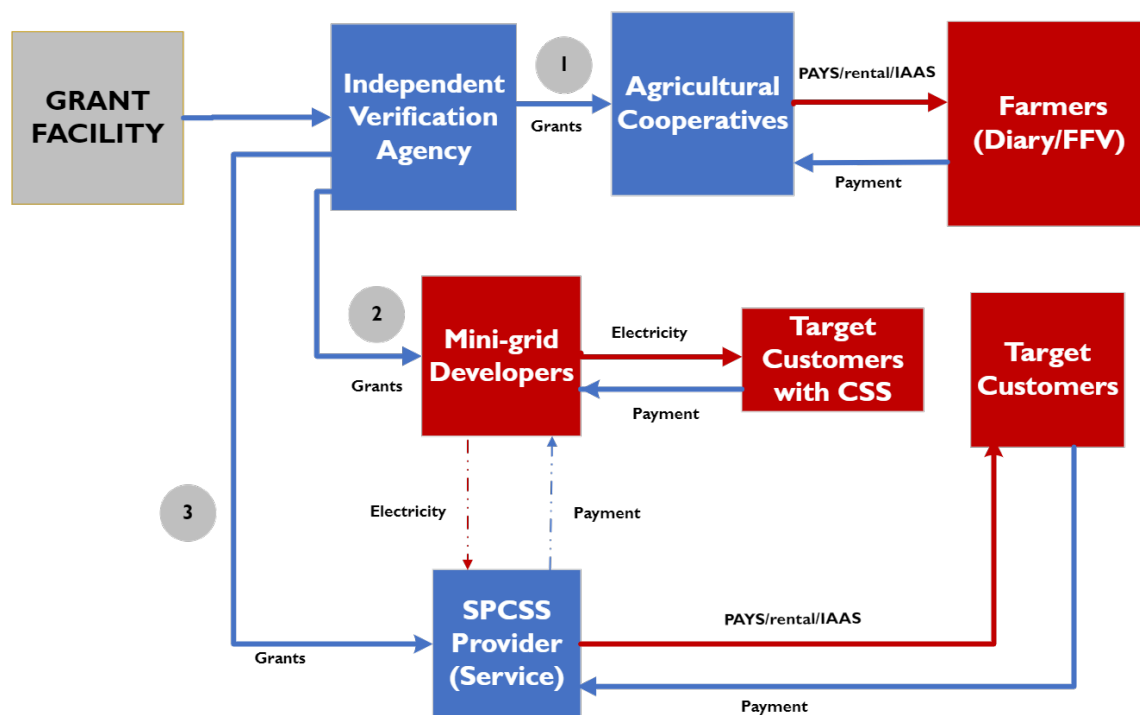
⁹⁵ Central Bank of Nigeria (2018). Guidelines for Commercial Agriculture Credit Scheme (CACCS). Source: <https://www.cbn.gov.ng/out/2018/fprd/cacs%20guidelines%20incorporating%20non%20interest%20banks.pdf>

GRANT FINANCING

Grant funding, typically provided by donor organizations and development finance institutions (DFIs) through the country's government, does not require repayment. Examples of donor organizations include the United States Agency for International Development (USAID) and UK Foreign, Commonwealth and Development Office (FCDO) while DFIs include the United States International Development Finance Corporation (US DFC), the CDC Group, Energizing Development (EnDev), the French Development Agency (AFD), and the Asian Development Bank (ADB). It reduces the capital costs associated with purchasing SPCSS and provides funds for technical support. Grants are crucial to the increased adoption of SPCSS across the country due to the high capital cost of cold storage equipment (Table 10). Grants are competitive and a limited number of recipients can ultimately receive funds, hence, other financing structures (debt financing and equity financing) are also important.

Grant facilities provide matching grants to selected grantees, through an independent verification agency, to reduce the capital cost associated with cold storage equipment purchase especially when projected cash flows indicate grant can improve business economic viability. The grant facility also funds an independent verification agency to verify and monitor grants disbursed. In addition to capital cost reduction, some grants are used to provide technical assistance through feasibility studies and capacity building programs. Grants can be administered in the form of result-based financing (RBF) or upfront payments.

Figure 7: SPCSS Grant Financing Structure



Result-based financing is a grant that is paid once the mini-grid developers have proven that the developed mini-grid is already providing electricity to the cold storage systems (i.e., on a per connection basis). In that case, the mini-grid developers make use of loans or internal funds to execute the project after which funds are disbursed based on the number of connections made. The examples below highlight some RBF available to support SPCSS procurement and facilitation.

- The Nigerian Electrification Project (NEP) is an initiative of the REA supported by the World Bank and African Development Bank (AfDB). It seeks to provide electricity access to households, as well as micro, small and medium enterprises in off-grid communities across the country through the adoption of renewable energy sources. The initiative provides grant facilities to private and public sector organizations which will enable the electrification of rural communities. Grant funding under NEP is performance-based and provides support to mini-grid developers as well as SHS distributors for the deployment of solar energy solutions across the country.
- The AfDB NEP Results Based Financing for Productive Appliances & Equipment, managed by REA, is aimed at increasing the productive use of electricity through the provision of productive use appliances (including cold storage systems) to 24,500 MSMEs in Nigeria. The total fund available under this program is NGN 8.2 billion (US\$20 million) targeted towards mini-grid developers with existing mini-grids in rural communities. The program is currently designed to provide a subsidy to mini-grid developers who purchase productive use appliances for their customer base. It is currently in a pilot phase and is scheduled for broader roll-out in the coming years.

Upfront Grants are grants disbursed to the recipient (mini-grid developer, SPCSS provider, farmer cooperatives) upfront and provided prior to the commencement of the project. Unlike the RBF, the upfront grants are not dependent on the achievement of particular milestones.

The examples below highlight some upfront grant opportunities that can be leveraged for the provision of mini-grids for powering cold storage equipment in off-grid communities:

- The Rural Electrification Fund (REF) administered by the Rural Electrification Agency (REA), was created to promote electricity access for unserved and underserved rural communities and is financed through budgetary allocations from the Nigerian Government. The REF grants between US\$10,000 to US\$300,000, or 75% of the total capital costs of the project to the mini-grid developers.
- The U.S. African Development Foundation (USADF) and All On Energy, provide funding to businesses looking to increase energy access to communities through the Nigerian Off-grid Energy Challenge Fund. The fund provides US\$50,000 in convertible debt and US\$50,000 in grant capital to businesses including mini-grid developers and SHS providers and can be used to provide off-grid energy to rural communities and most importantly smallholder farmers, for productive use (i.e. solar irrigation).

EQUITY FINANCING

Equity financing involves mini-grid developers, farm-produce aggregators, or SPCSS providers offering part ownership of their business (corporate equity) or a part of their project (project equity) in exchange for cash to finance capital costs, growth, and development.⁹⁶ Because specific payments such as fees or interest rates are not expected in return for equity financing, the ownership of the business is expected to deliver a return on the investment over time as the capital produces cashflows or the business grows in value. Farmer cooperatives can also provide equity financing for the provision of SPCSS by pooling together their financial resources and owning percentages of the system.

The main types of some equity investors are highlighted below:

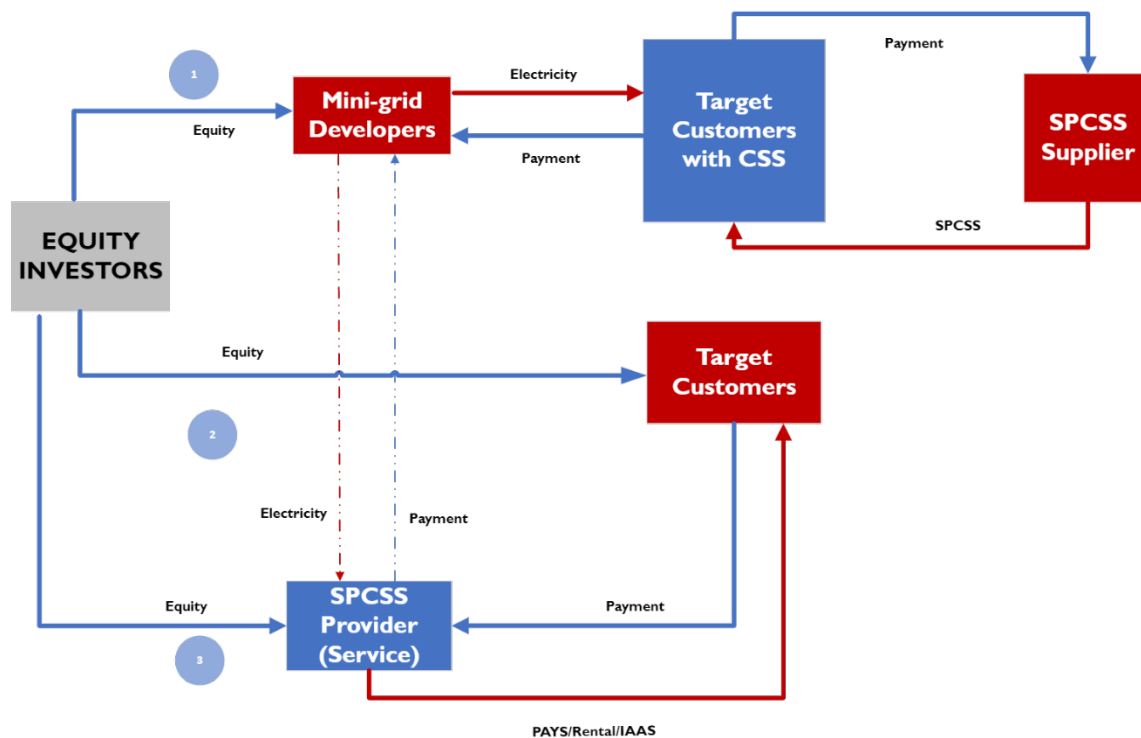
- **Development Finance Institution (DFI):** DFIs invest in projects or businesses which demonstrate developmental impact as well as commercial viability. DFIs seek to foster job creation and sustainable economic growth as such, investment in cold storage projects for the prevention of food losses, is logical. Examples of some DFIs that exist within Nigeria are the Bank Of

⁹⁶ Corporate Finance Institute (2020). "Equity Financing – Overview, Sources, Pros and Cons". Source: <https://corporatefinanceinstitute.com/resources/knowledge/finance/equity-financing/>

Agriculture (BOA), Bank of Industry (BOI), Development Bank of Nigeria (DBN), Nigerian Export-Import Bank (NEXIM), and the Infrastructure Bank.

- **Impact Investor:** Impact investors are equity financiers who invest in projects or businesses that have the potential to provide adequate financial returns as well as projects that aim for social impact. Examples of impact investors are Factor[e] Ventures, and All On Energy.
- **Venture Capitalist:** Venture capitalists are, in most cases, private equity investors who provide funds to early-stage startup companies with significant growth potential for an equity stake in the business. Venture capitalists are also capable of investing in cold storage projects provided the return on investment (ROI) is significant and the project demonstrates potential for sustainability.
- **Private Equity Investors:** Private equity investors, just like venture capitalists, seek to purchase equity stakes in businesses or projects. The major difference is Private equity investors target already established businesses who are seeking funds (whereas venture capitalists target startups). Private Equity Investors can potentially invest in the business of mini-grid developers or SPCSS service providers to offer cooling services (i.e. IAAS, PAYS) to target customers.

Figure 8: SPCSS Equity Financing Structure



BUSINESS CASE SCENARIO ANALYSIS

In order to better understand the economic viability of solar powered cold storage systems across various business models, PA-NPSP conducted an analysis examining and evaluating illustrative cold storage investment scenarios. The analysis models scenarios with different target customers across the cold storage value chain under four distinct business models, different powering options (solar vs. diesel) and seven different cold storage systems of varying capacities for the preservation of milk, fish, meat, FFVs, and ice production. Through this analysis, PA-NPSP seeks to gain insight into the economic viability of different cold storage systems and illustrate the business models which may apply under various scenarios.

VARIABLES

PA-NPSP selected the following variables to develop scenarios for testing cold storage systems and financing structures viability.

- **Cold storage system.** Scenarios include seven different cold storage systems of varying storage and production capacities: 38L/day, 500L/day, 8,000L/day, 96,000L/day, 13,281L/day, 14kg/day, 150kg/day.
- **Cold storage power.** Scenarios include three different types of power generation for cold storage systems: solar, diesel, and solar-diesel hybrid.
- **Commodities.** Scenarios model outputs for the preservation of four different commodity types: milk, fish, meat and FFVs.
- **Financing.** PA-NPSP assumes farmers, fishermen and SPCSS providers in each of the scenarios can acquire local loans to cover 75% of the upfront cost of cold storage systems, at a 22% interest rate. The analysis assumes entities can obtain grants or self-fund the remaining 25% of the capital cost.
- **Loan repayment.** In each scenario, loan repayment is estimated based on sales from cooled commodities or sales of ice/cold storage. Under Scenarios 1 – 3, the investing communities use profits earned from increased sales of preserved commodities (milk and fish) to make loan payments. It is assumed that 20% of sales of milk and fish can be attributed to cold storage. Under Scenarios 4 – 8 revenue earned from either PAYS or IAAS offered to target customers are used for loan repayment, after operating cost deductions. Operating costs include maintenance and other costs such as labor and shop rental costs.

Scenarios include shared community-owned, ice-as-a-service (IAAS), pay-as-you-store (PAYS), and commercial partner business models. Under the shared community-owned business models (Scenarios 1-3), a community collectively invests in the acquisition of a SPCSS, financing the purchase with both debt and grants, and uses profits from increased sales resulting from the equipment to pay back debt financing. Under the IAAS model (Scenario 4), an entity (e.g., an MSME) uses both debt and grants to finance the acquisition of an icemaker, sells ice to target customers (e.g., fishermen seeking to preserve fish), and repays debt using profits from ice sales. Under the PAYS model (Scenario 5-8), an entity uses both debt and grants to finance the acquisition of an SPCSS provider, sells cold storage as a service to target customers, and repays debt using profits from cold storage service sales. Under the commercial partner business model (Scenario 9), a cold storage service (CSS) provider who powers their CSS via diesel collaborates with a mini-grid developer to instead power their CSS via a solar-diesel hybrid system. The CSS provider then offers cold storage as a service to target customers who want to cool or freeze their produce.

Scenario analysis is based on cash flow modeling with assumed inputs from literature review and stakeholders' interviews. For small-scale cold storage systems (Scenarios 1 and 3) revenue is assumed profit for modeling simplification purpose and operating expenses such as maintenance, labor, and shop

rental are assumed to be negligible. In all scenarios, all additional profit attributable to the acquisition of the SPCSS will be available to pay back debt.

OUTPUTS

The outputs generated from the scenario analysis is as follows:

- **Net present value (NPV).** This is the present value of future cashflows from profit realized from investment over a 25-year project life, after the operating costs of the system and any debt service payments from financing (a NPV above zero is profitable).
- **Internal rate of return (IRR).** The IRR is the percent return on the upfront investment (capital cost) based on all future cashflows from profit realized over a 25-year project life, after the operating costs of the system and any debt service payments from financing (an IRR below zero is not financially viable).
- **Payback of capital cost.** This output is the number of years of profit from increased yield that are required to pay back the upfront capital cost, before taking financing or debt into consideration. This output indicates the time required to recover the upfront cost if the investing entity were to fully fund the equipment investment up front (without financing).
- **Average debt service coverage ratio (DSCR).** DSCR is the ratio of cashflows available for debt service (profit minus capital and operating costs) to debt service. It indicates the coverage the cashflows provide against annual debt payments. The output calculated is the average DSCR for all financing years.

COLD STORAGE SCENARIOS

PA-NPSP developed eight different scenarios for testing the economic viability of different commodities, cold storage systems, and business models. These scenarios are outlined below. Specific assumptions made for these scenarios and methodology are documented in Appendix C.

- **Scenario 1 – Solar-powered Dairy Refrigerator, Shared Community Model.** Under Scenario 1, a community of farmers acquires a standalone solar-powered dairy refrigerator (38L/day) for storing milk. The scenario assumes a 20% increase in profit is attributable to the use of the dairy refrigerator. The scenario assumes dairy farmers located in northern Nigeria own 54 milking cows jointly (cooperatives) and each cow produces 207L/year of milk (total milk produced by all cows is approximately 38L/day). The scenario assumes farmers can consistently sell milk for US\$1.85/L.
- **Scenario 2 – Solar-powered Milk Cooling Unit, Shared Community Model.** Under Scenario 2, a group of milk aggregators (entities which source milk from dairy farmers) acquires a standalone solar-powered milk cooling unit (500L/day) for storing milk. The scenario assumes a 20% increase in profit is attributable to the use of the cooling unit. The milk aggregators are able to use the full capacity of the milk cooling unit (500L/day) and consistently sell the milk for US\$1.85/L.
- **Scenario 3 – Solar-powered Ice Maker, Shared Community Model.** Under Scenario 3, a community of fishermen acquires a standalone solar-powered ice maker (14kg of ice /day) to produce ice for preserving fish. The scenario assumes a 20% increase in profit is attributable to the use of the ice maker. The scenario assumes 0.25 kg of ice can cool 1 kg of fish and therefore the fishermen are cooling 56kg of fish/day. The scenario assumes fishermen can consistently sell fish for US\$3.7/kg.
- **Scenario 4 – Diesel-powered Ice Maker, Ice-as-a-service Model.** Under Scenario 4, an MSME acquires a diesel-powered ice maker (150 kg of ice /day) to produce ice for preserving fish.

The MSME sells ice to customers at US\$0.4/kg. The scenario assumes that all profit from ice sales (revenue minus operating costs) are available for annual loan payments.

- **Scenario 5 – Solar-powered Refrigerated Trailer, Pay-as-you-store Model.** Under Scenario 5, an MSME acquires a solar-powered 48ft trailer to offer cooling as service (96,000L/day) to logistics customers for the preservation of FFV and milk. The MSME charges US\$0.24 per crate of produce stored per day. The trailer is capable of storing 1,089 crates at a time. The scenario assumes that all profit from cooling storage sales (revenue minus operating costs) are available for annual loan payments.
- **Scenario 6 – Diesel-powered Freezer, Pay-as-you-store Model.** Under Scenario 6, an MSME acquires a diesel-powered freezer to offer freezing as service (8,000L/day) to target customers for the preservation of meat and fish. The MSME charges US\$1.00 per crate stored per day. The freezer is capable of storing 113 crates at a time. The scenario assumes that all profit from freezing service sales (revenue minus operating costs) are available for annual loan payments.
- **Scenario 7 – Solar-powered Cold Room, Pay-as-you-store Model.** Under Scenario 7, an MSME acquires a solar-powered cold room (13,281L/day) to offer cooling as service to target customers for the preservation of FFV. The MSME charges US\$0.33 per crate stored per day. The freezer is capable of storing 150 crates at a time. The scenario assumes that all profit from freezing service sales (revenue minus operating costs) are available for annual loan payments.
- **Scenario 8 – Solar-powered Freezer, Pay-as-you-store Model.** Under Scenario 8, an MSME acquires a solar-powered freezer (8,000L/day) to offer freezing as service to target customers for the preservation of meat and fish. The MSME charges US\$1.00 per crate stored per day. The freezer is capable of storing 113 crates at a time. The scenario assumes that all profit from freezing service sales (revenue minus operating costs) are available for annual loan payments.

Table 11: Cold Storage Business Case Scenarios

No.	Product	System	Capacity	Model	CAPEX (USD)
1	Milk	Refrigerator	38L/day	Shared community	\$4,992
2	Milk	Cooling Unit	500L/day	Shared community	\$28,841
3	Fish	Ice maker	14kg/day	Shared community	\$2,927
4	Fish	Ice maker	150kg/day	Ice-as-a-service	\$7,929
5	FFV, Milk	Cold Trailer	96,000L/day	Pay-as-you-store	\$166,883
6	Fish, Meat	Blast Freezer	8,000L/day	Pay-as-you-store	\$23,540
7	FFV, Milk	Cold Room	13,281L/day	Pay-as-you-store	\$30,100
8	Fish, Meat	Blast Freezer	8,000L/day	Pay-as-you-store	\$34,498

SCENARIO ANALYSIS RESULTS

Table 12 presents financial results for each business case scenario. The results from this analysis indicate 1, 2, 3, 5, 8 as financially viable with high IRRs, positive NPVs, and average DSCRs above 1.5. The most opportune of these scenarios is Scenario 3 where the high annual revenue from increased sales of preserved fish is possible as a result of a relatively low upfront capital cost investment in an ice maker. This relationship is so powerful that even if only 2% of fish sales was reserved for investment repayment, the scenario would still result in an IRR of 24%. In Scenario 5, the high upfront capital cost of the cold trailer is feasible given the resulting annual revenue of approximately US\$ 89,000 in the first year. The daily price per crate can fall as low as ~US\$0.21 and this scenario still results in a 20% IRR. The high cost of diesel fuel and fuel price escalation as well as high operating costs are the drivers of unfavorable results in Scenarios 4, 6, and 7.

Table 12: Business Case Scenario Analysis Results

No	CAPEX (USD)	Annual Revenue Attributable to CSS (USD)	NPV (USD)	IRR (%)	Payback (Years)	Average DSCR
1	\$4,992	\$4,218	\$60,884	63%	2.00	3.35
2	\$28,841	\$55,500	\$536,000	148%	1.00	6.43
3	\$2,927	\$14,090	\$275,657	457%	1.00	19.41
4	\$7,929	\$20,400	(\$658,701)	<0%	25.00	-2.11
5	\$166,883	\$88,862	\$340,554	27%	3.00	1.93
6	\$23,540	\$38,420	(\$936,157)	<0%	25.00	-0.13
7	\$30,100	\$16,690	(\$118,551)	<0%	11.00	1.51
8	\$34,498	\$38,420	\$168,592	71%	3.00	3.70

Powering a cold storage system (blast freezer) via solar instead of diesel improves the profitability of this scenario option as illustrated by Scenario 8. The revenue is the same in Scenarios 6 and 8, and the CAPEX is even 46% higher in Scenario 8 as compared to Scenario 6, but Scenario 8 is unburdened by the cost of fuel and escalation of that cost over the life of the project. At a PAYS rate of US\$1/crate/day in Scenario 8, investors are able to offer an affordable rate to their customers while still recovering the cost of their capital investment within three years with a 71% IRR. In Scenario 7, investment in a solar-powered cold room is only profitable if the PAYS rate is increased to at least US\$0.45/crate/year (original rate US\$0.33/crate/year), in which case the IRR increases to 2% and investors can recover the capital investment in six years before financing.

Additional Blast Freezer Analysis

PA-NPSP conducted further analysis on Scenario 6 to assess the impact on financial viability of a shift in CSS power generation from diesel generation to solar mini-grid. As discussed above, CSS offers an opportunity to solar mini-grid developers to increase mini-grid viability through the addition of anchor or productive use loads. Table 13 presents a cost comparison of annual powering costs of the Scenario 6 blast freezer by diesel versus solar-diesel mini-grid hybrid at different mini-grid tariff rates. Under the solar-diesel hybrid system, it is assumed the diesel generator will run for 17 hours while a 45kW mini-grid with an assumed 50% underutilization rate, powers the blast freezer during the daytime, for 8 hours. Because of the high cost of diesel and high fuel escalation, over the 25-year life of the project, the solar-diesel hybrid scenarios do not meaningfully improve the economic feasibility of Scenario 6.

Table 13: Solar-diesel Hybrid Scenarios

Fuel / Power Generation Scenario	Powering Cost (USD/year)
Scenario 6, diesel fuel cost @ US\$0.59/L	\$29,368
Solar-diesel hybrid mini-grid @ US\$0.5/kWh	\$31,002
Solar-diesel hybrid mini-grid @ US\$0.44/kWh	\$29,778
Solar-diesel hybrid mini-grid @ US\$0.34/kWh	\$27,738

Table 14 illustrates the thresholds at which positive IRRs hold for variations in assumed revenue under each scenario. IRR outcomes in Scenarios 1 and 3 for example are highly resilient against reductions in revenue, maintaining positive IRR up to 60% reduction in assumed annual revenue. After a 20% increase in revenue, Scenario 7 achieves a positive IRR. Table 15 illustrates the impact of an increase in the size of the grant assumed (baseline = 25%) on the ability for the entity to cover annual debt service payments. Scenarios 5 and 7 are the only scenarios which are on the edge of viability in the baseline case but become meaningfully more viable with an increase in the size of the grant up to 50%.

Table 14: Impact of Variation in Revenue on IRR

Revenue Variation	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
-70%	<0%	<0%	121%	<0%	<0%	<0%	<0%	<0%
-60%	14%	<0%	168%	<0%	<0%	<0%	<0%	<0%
-50%	23%	7%	216%	<0%	<0%	<0%	<0%	<0%
-40%	32%	69%	264%	<0%	<0%	<0%	<0%	<0%
-30%	39%	89%	312%	<0%	<0%	<0%	<0%	10%
-20%	47%	109%	361%	<0%	<0%	<0%	<0%	4%
-10%	55%	129%	409%	<0%	21%	<0%	<0%	59%
Baseline	63%	148%	457%	<0%	27%	<0%	<0%	71%
10%	71%	168%	505%	<0%	33%	<0%	<0%	82%
20%	79%	187%	553%	<0%	39%	<0%	10%	93%

Table 15: Impact of Increased Grant on Average DSCR, Sensitivity Analysis

Grant Size	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
0%	2.51	4.82	14.56	-1.59	1.45	-0.10	1.15	2.78
5%	2.65	5.07	15.32	-1.67	1.53	-0.10	1.21	2.92
10%	2.79	5.36	16.18	-1.76	1.61	-0.11	1.28	3.08
15%	2.96	5.67	17.13	-1.87	1.71	-0.12	1.35	3.27
20%	3.14	6.02	18.20	-1.98	1.81	-0.12	1.44	3.47
<i>Baseline</i>	3.35	6.43	19.41	-2.11	1.93	-0.13	1.53	3.70
30%	3.59	6.89	20.80	-2.27	2.07	-0.14	1.64	3.97
35%	3.87	7.41	22.40	-2.44	2.23	-0.15	1.77	4.27
40%	4.19	8.03	24.26	-2.64	2.42	-0.16	1.92	4.63
45%	4.57	8.76	26.47	-2.88	2.64	-0.18	2.09	5.05
50%	5.03	9.64	29.12	-3.17	2.90	-0.20	2.30	5.55

Based on the results from the scenario analysis and the ability for farmers to raise funds from additional crop yields, PA-NPSP recommends the following for potential deployment models under each scenario. Fundraising can take place at the farmer level or at the level of an entity that is aggregating funds to achieve sufficient volume for a fundraise. In case of the latter, there must be sufficient overall returns (as is the case in Scenarios 1, 2, 3, 5 and 8) so that cashflows can be spread across the multiple entities involved i.e. the aggregator and the farmer.

Table 16: Deployment Models Most Relevant to Business Case Scenarios

Deployment Model	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
1. Non-Commercial Entity Model			X	X	X	X	X	
2. Commercial Partner Model	X	X						X
3. Developer-Owned Model	X	X						X
4. Shared Community-Owned Model			X	X	X	X	X	
5. SPCSS Provider-owned Model	X	X						X

While this analysis provides some insight into the potential economic impacts of solar powered cooling as productive use anchor loads in Nigeria, additional study is critical to understanding these impacts in greater depth and in various unique contexts across the country.

CONCLUSIONS AND RECOMMENDATIONS

The results of the business case analysis reveal a wide variation in the economic viability of investing in cold storage across different types of equipment, business models, and financing. Based on the analysis, investing in solar powered cold rooms under a PAYS model at rates comparable to those currently operating in Nigeria, is not profitable under a 75% debt financing structure. That said, in four of the eight scenarios tested (1, 2, 3, and 8) the grant volume could be reduced to 0% (100% debt financing) and borrowers would still achieve at least a 1.5x debt service coverage ratio. Debt financing presents a meaningful solution to farmers, fishermen, and other operators that are positioned to benefit from the CSS investments, but unable to afford the upfront capital cost. SPCSS service providers can reduce powering costs by partnering with mini-grid developers under commercial partnership models via solar-diesel hybrid systems, but it is important that a thorough investigation is conducted regarding the long term escalation of fuel costs and the exact volume of diesel fuel generation required. For sustainable deployment of SPCSS in Nigeria, PA-NPSP recommends the following interventions:

- **Consideration of environmental impacts of cold storage technologies:** In order to maintain environmental sustainability, SPCSS users, as well as donors and governments funding SPCSS, should be cognizant of the Global Warming Potential (GWP) of refrigerants associated with different cold storage options, comparing HFOs, blended HFCs, ammonia, and CO₂ with traditional HCFCs and HFCs. Any use of systems which require refrigerants with GWP should be paired with international best practices for operations, maintenance, and end-of-life management.
- **Understanding of costs, benefits, and deployment models:** When assessing the best deployment model for investing in and implementing SPCSS, users and funders should take due consideration of PAYS rates, operating costs such as fuel requirements, and escalation costs. As evidenced by the analysis above, some models may require high PAYS rates to achieve financial viability and these rates must be validated with customer willingness and ability to pay before an investment decision is made.
- **Awareness campaigns:** Given the complex nature and high number of different cold storage systems, it is necessary that users and customers are equipped with relevant knowledge of costs, potential benefits, suitability, deployment models, and financing options to allow for sound decision making. Governments and donor funded programs should engage facilitators to undertake awareness creation campaigns leveraging local knowledge networks to spread information and increase acceptance of SPCSS among potential users to increase the effectiveness of these solutions.
- **Targeted financing and awareness campaigns for marginalized customers:** While SPCSS offers business investment opportunities for women entrepreneurs, farmers, and fishermen, hard-wired energy systems such as cold storage systems, tend to target men, limiting women's ability to take advantage of benefits from such investments. Governments and donor funded programs can mitigate this imbalance through strategic awareness campaigns for women. Governments and donor funded programs can also offer specialized financing opportunities specifically for women who are 13 times less likely to own land (a critical collateral for accessing commercial loans).
- **Further analysis of location-specific business models:** There is an opportunity for the off-grid stakeholder community to further develop location specific, data-driven business models for cold storage given different states require different types of cold storage, based on the type of commodities produced and transported.

APPENDICES

APPENDIX A: SUMMARY OF COLD STORAGE PROJECTS BY COUNTRY

Geography	Technology	Developer	Investors/ Donors	Description	Business Model
Africa, Asia, and South and Central America	Cold room	InspiraFarms	SunFunder (Debt financing)	<p>Utilizes thermal storage (referred to as an ice battery) to keep produce cool and fresh, even in the absence of consistent electricity</p> <p>Reduces PHL as well as energy costs, and helps farmers gain access to higher value markets.</p> <p>More than 5,000 members of rural communities in developing countries have experienced improved livelihoods, especially the women in underserved communities that now have jobs.</p>	<p>Blended debt fund</p> <p>Pay-as-you-chill</p> <p>Facilitator: Facilitating the connection between smallholder farmers, on-demand users, and markets and commercial opportunities.</p>
Ethiopia	Cold storage	Alemu Assefa Solar Enterprise	USAID	*Installing solar cold storage facilities to Dek Island and the surrounding areas of Lake Tana, outside of concentrated populated areas.	<p>Renting: Fishermen and farmers will pay a rental fee for use of the facilities.</p> <p>Grant: The company received a grant of US\$100,000 from USADF to support the project.</p>
Ethiopia	Solar cold room, 12kW	Rensys Engineering and Trading	USADF/ USAID	*Installing a refrigerator for cold storage purposes for fishermen.	Grant: The company received a grant to support the project.
Ghana	Solar cold storage	Atlas Business and Energy Systems Limited	USAID	*Planned Construction and operation of a solar powered facility that will provide cold storage services to fishermen.	Grant: The company received a grant to support the project.

Geography	Technology	Developer	Investors/ Donors	Description	Business Model
India	Milk Chillers, 5kW – 12.4kW	Promethean Power Systems	Acumen (Impact investment funding) Invested Development Total Carbon Neutrality Ventures	<p>Milk can be chilled gradually over time, in multiple stages, or in a matter of seconds. Its Thermal Storage System allows for the preservation of produce in the absence of a constant electricity supply without resorting to diesel-powered generators.</p> <p>Installed 1,200 units, which has served 60,000 farmers, chilled 700,000,000 liters of milk, and saved 3,000,000 liters of diesel.</p> <p>Increase in revenue generation, profit margins via cost reductions and advancement of agribusinesses.</p>	Technology supplier: Supplies milk chillers of varying capacity to customers (off-takers and milk processors)
Nigeria	Solar cold room, 5.7kW	ColdHubs	GIZ, Factor[e] and Fledge	<p>ColdHubs is a solar-powered walk-in cold room that preserves perishable agricultural produce off-grid. They are designed to operate in rural areas and are installed in markets and farms.</p> <p>Farmers increase their revenue from augmenting the volume of produce sold. It enables them to sell their produce at market value, as opposed to selling them at discounted rates due to damage or risk of spoilage.</p> <p>Creates employment and income generating opportunities for smallholder female farmers by recruiting and training them to work as ColdHubs operators.</p> <p>It reduces daily labor costs for harvesting and transportation from 5 hours per day to 1 hour per day by eliminating the need to return to the farm to store unsold, harvested</p>	Pay-as-you-store: Where customers are charged a flat rate of NGN 100 (US\$0.20) per day for each crate of food they store.

Geography	Technology	Developer	Investors/ Donors	Description	Business Model
				produce or to harvest additional produce for sale.	
Nigeria	Solar cold storage, 8kW	TransAfrica Gas and Electric (TAGE)	USAID	TAGE won a USAID grant in 2014 to provide solar-powered cold storage equipped for ice making to communities in Northern Nigeria. Its aim is to provide a means for local farmers to store and cool their produce before transporting them to be sold in the local markets. The facility will be powered by an 8 kilowatt (kW) solar photovoltaic system. Farmers will then pay a small fee to warehouse their products and will purchase ice to preserve daily produce. ⁹⁷	<p>Technology supplier: Constructs standalone cold storage facility for the preservation of all types of vegetables, fish, and poultry</p> <p>Grant: The company received a grant to support the project.</p>
Rwanda	Solar cold storage for 40 dairy and livestock processing units	Dassy Enterprise	USAID	*Dassy Enterprise is to install solar cold storage for 40 dairy and livestock processing units in the Gishwati Highlands.	<p>Grant: The company received a grant to support the project.</p>

(US\$1 - NGN 502)

* Installation and impact unconfirmed

⁹⁷ Power Africa (2017). "Power Africa Off-Grid Energy Grants Portfolio". Source: <https://static1.squarespace.com/static/564bee8de4b05dd815f0baa0/t/58d12fefe6f2e1c8a6b3dbc4/1490104305501/Power+Africa+External+Briefing+Sheet+1-1-2017.pdf>

APPENDIX B: DEBT AND GRANT FINANCING SCHEMES

Name of PFI	Loan Tenure	Loan Amount	Loan Interest Rate	Eligibility
Lift Above Poverty Organization Microfinance Bank (LAPO MFB) ⁹⁸	12 – 14 months	NGN 50,000 to NGN 500,000 (US\$ 121.95 to US\$1,219.51)	0.75 – 6%	Smallholder farmers
Grooming Center ⁹⁹	6 months	NGN 250,000 to NGN 750,000 (US\$609.76 to US\$1,829.27)	14%	Smallholder farmers
Small and Medium Enterprises Development Agency of Nigeria (SMEDAN) ¹⁰⁰	30 months	NGN 1.2 million to NGN 5 million (US\$2,926.82 to US\$12,195.12)	9%	Micro and Small and Medium-size Enterprises (MSEs) i.e. SPCSS service provider
Bank of Agriculture (BOA) - Direct Credit Product loan ¹⁰¹	60 months	NGN 250,000 to NGN 50 million (US\$609.76 to US\$121,951.22)	14% (for Agricultural production and agro-processing) 20% (for commodity marketing)	Smallholder farmers, MSMEs, large agribusinesses (corporate entities)
Bank of Agriculture (BOA) - Large Credit Product Loan ⁹⁶	60 months	NGN 50 million to NGN 1 billion (US\$121,951.22 to US\$2.4 million)	14% (for Agricultural production and agro-processing); 20% (for commodity marketing)	Large agribusinesses (corporate entities)

⁹⁸ Lift Above Poverty Organization Microfinance Bank (LAPO MFB) (2015). Agric Loans. Source: <https://www.lapo-nigeria.org/loans/agric>

⁹⁹ Grooming Centre (2017). Source: <https://groomingcentre.org/products/>

¹⁰⁰ Small and Medium Enterprises Development Agency of Nigeria (SMEDAN) (2021). “SMEDAN, BOA Target MSMEs with Matching Fund Program”. Source: <https://smedan.gov.ng/smedan-boa-target-msmes-with-matching-fund-programme/>

¹⁰¹ Bank of Agriculture (2020). “Direct Products and Services (Small and Medium Enterprises)”. Source: <http://www.boanig.com/services/>

Name of PFI	Loan Tenure	Loan Amount	Loan Interest Rate	Eligibility
Bank of Agriculture (BOA) - Agricultural Micro-loan ⁹⁶	24 months	Up to NGN 250,000 (US\$609.76)	12% per year	Horticulture and livestock farmers, traders, fisheries etc.
Agric-Business Small and Medium Enterprise Investment Scheme (AGSMEIS) ¹⁰²	84 months	Up to NGN 10 million (US\$24,390.24)	5%	Agric-Business Small and Medium Enterprise
Commercial Agriculture Credit Scheme (CACS) ¹⁰³	Maximum tenor based on gestation period of enterprise/or working capital facility of one year with provision for roll over. ¹⁰⁴	NGN 1 billion (US\$2.45 million)	9%	Banks and State Governments
Private Sector-Led Accelerated Agriculture Development Scheme (P-AADS) ¹⁰⁵	72 months (for annual crops), 120 months (for perennial crops)	NGN 2 billion (US\$4.9 million)	9%	Private sector agricultural producers of staple foods and industrial raw materials

¹⁰² Adetiloye, D (2020). "Apply for ₦10 million AGSMEIS 5 percent Loan Today." Source: <https://www.dayoadetiloye.com/apply-for-n10-million-cbn-agsmeis-5-loan-today/>

¹⁰³ Central Bank of Nigeria (CBN) (2018). Guidelines for Commercial Agriculture Credit Scheme (CACS). Source: <https://www.cbn.gov.ng/out/2018/fprd/cacs%20guidelines%20incorporating%20non%20interest%20banks.pdf>

¹⁰⁴ Central Bank of Nigeria (CBN) (2018). Commercial Agriculture Credit Scheme: Evaluation and Impact Assessment Report. Source: https://www.cbn.gov.ng/Out/2018/STD/CACS%20Evaluation%20and%20Impact%20Assessment%20Report_compressed.pdf

¹⁰⁵ Premium Times (2020). "CBN launches another program to provide up to ₦2 billion loan to farmers." Source: <https://www.premiumtimesng.com/agriculture/agric-news/425907-cbn-launches-another-programme-to-provide-up-to-n2-billion-loan-to-farmers.html>

Name of PFI	Loan Tenure	Loan Amount	Loan Interest Rate	Eligibility
Anchor Borrowers' Program (ABP) ¹⁰⁶	Gestation period of the identified commodities	Amount for each smallholder farmer shall be determined by the economics of production agreed with stakeholders.	9%	Smallholder farmers

¹⁰⁶ Central Bank of Nigeria (CBN) (2016). Anchor Borrowers' Program Guidelines. Source: <https://www.cbn.gov.ng/out/2017/dfd/anchor%20borrowers%20programme%20guidelines%20-dec%20%202016.pdf>

APPENDIX C: BUSINESS CASE ANALYSIS ASSUMPTIONS

This appendix presents an overview of the methodology used to assess the economic feasibility of cold storage system investment for the preservation of milk, fish/meat and FFVs.

CAPITAL AND OPERATING COST ESTIMATES

The initial capital cost, operating and maintenance cost associated with SPCSS investment is estimated and used to determine the NPS, IRR, Payback period, and Average DSCR through cash flow modelling over a 25-year project life.

Table 17: Scenario Analysis Capital Cost Assumptions

No.	Equipment	Description	¹⁰⁷ Cost (USD)	Source/Assumption
1	Solar-powered dairy refrigerator	<ul style="list-style-type: none"> Equipped with 2 modules of 200W panels. Battery-less system 185Wh/day energy consumption 38 liters per day cooling volume 	\$4,992	Photovoltaics for Productive Use Applications (2016). A Catalogue of DC-Appliances.
2	Solar-powered milk cooling unit	<ul style="list-style-type: none"> 500 liters per day cooling volume 3.5kW PV panel Lead battery (33.6 kWh) Battery replacement after 5 years @US\$10,000 	\$28,841	Moffat, F et. al. (2016). Technical and investment guidelines for milk cooling, FAO.
3	Solar-powered ice maker	<ul style="list-style-type: none"> 1,340 Wh/d energy consumption Equipped with 400W PV panels 65Ah battery Ice production of up to 14 kg/day 	\$2,927	Photovoltaics for Productive Use Applications (2016). A Catalogue of DC-Appliances.
4	Ice maker	<ul style="list-style-type: none"> 4.5kW energy consumption Ice production of up to 50 ice blocks (50kg) blocks in 8 hours Cost excludes PV system 70 liters diesel tank capacity Diesel consumption of 5 liters for 4 hours 	\$3,414 \$4,515	De Kooler Nigeria Price List Jiji Brand New 18KVA Soundproof Diesel Generator
5	Solar-powered refrigerated trailer	<ul style="list-style-type: none"> 48-ft, ~ 77,000 liters cooling volume Electric system with Solar PV (5.5kW) and Battery (80kWh) 	\$165,884	Wabash National, Diesel-only vs. eNow Zero-Emission Trailer Solaris, LG Solar Lithium Ion Battery
6	Blast freezer	<ul style="list-style-type: none"> 8,000 liters freezing volume 7.5kW energy consumption Freezes within 30-90mins 30kVA Diesel generator (to power 7.5kW blast freezer) 	\$16,833 \$6,707	De Kooler Nigeria Price List Jumia Generators
7	Solar-powered cold room	<ul style="list-style-type: none"> 13,281 liters per day cooling volume Batteries are charged by solar panels generating about 5.7 kWh 	\$30,100	Engineering for Change, Cold Hubs Watt U Need, Lithium Battery
8	Solar-powered blast freezer	<ul style="list-style-type: none"> 8,000 liters freezing volume 7.5kW energy consumption Freezes within 30-90mins Inverter (9kW) 9kW PV panels Lithium battery storage (19.6kWh) 	\$34,498	SunWatts Solar Inverters Solaris, LG Solar Lithium Ion Battery

¹⁰⁷ Updated to 2021 with 7.5% added as VAT

Table 18: Scenario Analysis Operating Cost Assumptions

Scenario	Cost (USD/year)	Source/Assumption
Scenario 1 and 3	-	Assumed no shop rental and labor is required since equipment is procured for personal cooling and no service is offered.
Scenario 2	US\$5,269	<ul style="list-style-type: none"> Two personnel for milk cooling @ US\$2,341/year¹⁰⁸ Shop rental @ US\$2,927/year¹⁰⁹
Scenario 4	US\$ \$21,637	<ul style="list-style-type: none"> Two personnel for ice block operating @ US\$2,341/year Shop rental @ US\$2,927/year Fuel cost @ US\$16,369/year = Fuel price US\$0.59/L * fuel consumption for 18kVA generator of 3.4L/hour
Scenario 5	US\$5,269	<ul style="list-style-type: none"> Two personnel for refrigerated trailer @ US\$2,341/year Land rental @ US\$2,927/year Fuel cost for trailer transportation not included
Scenario 6	US\$34,636	<ul style="list-style-type: none"> Two personnel for freezer operation @ US\$2,341/year Shop rental @ US\$2,927/year Fuel cost @ US\$29,368/year = Fuel price US\$ 0.59/L * fuel consumption for 30kVA generator of 6.1L/hour¹¹⁰
Scenario 7	US\$4,098	<ul style="list-style-type: none"> One personnel for cold room @ US\$1,171/year Shop rental @ US\$2,927/year
Scenario 8	US\$5,269	<ul style="list-style-type: none"> Two personnel for freezer operation @ US\$2,341/year Shop rental @ US\$2,927/year
After-sales service and maintenance (all CSS)	1.5% capital cost	Assumed after-sales service and maintenance as 1.5% of capital cost. It assumed the aftersales cost for cold storage includes technical support from the manufacturer. Heavy duty repairs are not inclusive of this estimate.

¹⁰⁸ Above minimum wage (US\$ \$878)

¹⁰⁹ <https://nigeriapropertycentre.com/for-rent/commercial/shops/showtype>

¹¹⁰ <https://www.ablesales.com.au/blog/diesel-generator-fuel-consumption-chart-in-litres.html>

CASHFLOW INPUT ASSUMPTIONS

Table 19: Scenario Analysis Cashflow Input Assumptions

Assumptions	Input	Explanations
Inflation rate	12%	Based on 2020 inflation rate in Nigeria. Cash flow is in US\$; initial exchange rate of NGN 410 to US\$1.
Discount rate	4%	Assumed based on interest rate range (2-6%) for bank savings in Nigeria
Profit escalator	3%	Assumed profit margin for local markets in Nigeria range from 1-6%
Fuel price escalator	8%	Assumed based on average rate of increase in diesel price from 2014 till 2020
Tariff (electricity price) escalator	6%	Assumed rate at which mini- grid electricity price will increase each year.
Project life (years)	25	Assumed to be greater than the lifespan of PV panels to capture project return on investment more accurately.
Solar panel life (years)	20	After 20 years, panels work at about 90% of its original output.
Battery life, Lead acid (years)	5	Lifespan of lead acid batteries is 3-5 years
Refrigerator life (years)	15	Lifespan of refrigerators/freezers ranges from 10-20 years
Ice block maker life (years)	10	Lifespan of refrigerators/freezers ranges from 10-20 years
Diesel generator life (years)	6	Estimated lifetime ranges from 20,000 - 80,000 hours It is assumed the generator runs for 24hours a day 340 days a year.
Batter inverter life (years)	10	Life span of inverter is 10-15 years
Cold room, solar trailer life (years)	10	Lifespan of Lithium battery is 5-15 years
45kW mini-grid load utilization factor	50%	It is assumed the mini-grid paired for electrifying blast freezer is 50% underutilized and thus capable of powering a 7.5kW blast freezer during the daytime
45kW mini-grid tariff (US\$/kWh)	0.34–0.86	Assumed estimate based on tariff range of US\$0.34–0.86/kWh for mini-grids in Nigeria
Loan interest rate	22%	Based on interest rates for observed agricultural bank loans ranging from 5% to 40%. ¹¹¹
Loan tenor (years)	5	Based on observed average loan tenors for agricultural loans in Nigeria.
Grid extension	-	Grid extension cost was not factored into the cash flow inputs. It is highly dependent on local circumstances, population densities, and distances.

¹¹¹ Start credit (2021). https://startcredits.com/free-loan-search/?swoof=1&product_cat=micro-finance&product_tag=group_loan-nigeria

Table 20: Business Case Scenario Revenue Calculations

Scenario	Revenue (USD/year)	Calculation
1	\$4,212	<ul style="list-style-type: none"> • 20% of milk sales revenue attributable to cold storage (see Table 2) • 300 milking days/year¹¹² • 54 cows • 213kg of milk/cow/year¹¹³ • 1 kg of milk = 0.971 L of milk • (213kg * 54 cows * .97)/300 = ~38L/day • Price of milk / L = US\$ \$1.85 38L * US\$1.85 * 20% * 300 days = US\$4,212
2	\$55,550	<ul style="list-style-type: none"> • 20% of milk sales revenue attributable to cold storage (see Table 2) • 300 milking days/year • 1 kg of milk = 0.971 L of milk • Cooling unit capacity = ~500L/day • Price of milk / L = US\$ \$1.85 500L * US\$1.85 * 20% * 300 days = US\$55,550
3	\$14,090	<ul style="list-style-type: none"> • 20% of fish sales revenue attributed to cold storage • 0.25kg of ice can cool 1 kg of fish¹¹⁴ • Icemaker produces 14 kg of ice/day • 14kg ice /0.25kg of fish cooled kg of ice = 56kg of fish cooled/day • Days of operation / year = 340 • Price of fish / kg = US\$3.7 56kg * US\$3.7 * 20% * 340 days = US\$14,090
4	\$20,400	<ul style="list-style-type: none"> • 150kg ice produced/day • 340 days operational/year¹¹⁵ • Price of ice US\$ \$0.4 150kg * US\$ 0.4 * 340 days = US\$20,400
5	\$88,862	<ul style="list-style-type: none"> • Pay-as-you-store charges of US\$0.24/day • Crate volume is of 53L • 1,089 crate capacity of cold trailer • 340 days of operation/year 1,089 crates * US\$0.24/day/crate * 340 days = US\$88,862/year
6, 8	\$38,420	<ul style="list-style-type: none"> • Pay-as-you-store charges of US\$1/day • Crate volume of 53L • 113 crate capacity of blast freezer • 340 days of operation/year 113 crates * US\$1/day/crate * 340 days/year = US\$38,420/year
7	16,830	<ul style="list-style-type: none"> • Pay-as-you-store charges of US\$0.33/day • Crate volume of 53L • 150 crate capacity of the cold room • 340 days of operation/year 150 crates * US\$0.33/day/crate * 340 days/year = US\$16,830/year

¹¹² Source: <http://www.milkproduction.com/Library/Scientific-articles/Housing/Cow-comfort-15/>

¹¹³ Source : Santana, S.; Allee, A.; Meng, Z.; Omonuwa, W.; Sherwood, J.; Balaji, M. K.; Rosi-Schumacher, K. (2020). "Agricultural Productive Use Stimulation in Nigeria: Value Chain & Mini-Grid Feasibility Study". Rocky Mountain Institute, Deloitte Consulting LLP. Prepared for the U.S. Agency for International Development Power Africa Nigeria Power Sector Program

¹¹⁴ <http://www.fao.org/3/v7180e/v7180E0e.htm>

¹¹⁵ Based on production plant principle. Allowing a number of days in a year to enable plant maintenance and repairs. Coulson, J. M., Richardson, J. F., & Coulson, J. M. (1999). Coulson & Richardson's chemical engineering. Oxford: Butterworth-Heinemann.