A PROPOSAL FOR THE DEVELOPMENT OF SMART SOLAR-POWERED COLD STORAGE UNITS FOR SUSTAINABLE POST-HARVEST MANAGEMENT

SUBMITTED FOR

The NASENI Research Commercialization Grant

BY

Dr. Ngozi Fidelia EFOZIA
Principle Investigator

16TH SEPTEMBER, 2025

EXECUTIVE SUMMARY

This project seeks funding to develop and deploy smart solar-powered cold storage units as an affordable, accessible, and sustainable solution to Nigeria's post-harvest losses. Leveraging renewable energy and innovative design, the cold rooms will be locally fabricated using over 70% indigenous materials, integrating solar power, Phase Change Materials (PCM) for thermal storage, and eco-friendly refrigerants to ensure cost-effectiveness and environmental sustainability.

The development process will progress through design, prototyping, and rigorous field testing, culminating in a pilot deployment in rural agricultural hubs before scaling up to commercial levels. A distinctive innovation is the integration of Industry 4.0 technologies, including IoT-based sensors for real-time monitoring, predictive analytics for preventive maintenance, and a cloud-based dashboard to optimize inventory and performance. These features will extend the shelf life of perishables by up to 200%, reduce farmer losses by 40–60%, and improve supply chain reliability.

The primary beneficiaries are smallholder farmers, agro-cooperatives, and rural market traders—groups disproportionately excluded from existing cold storage solutions, which are typically diesel-powered, urban-centered, costly, and environmentally damaging. By contrast, our solution offers sustainability, affordability, and smart technology, directly addressing rural producers' needs while creating new income opportunities. With each unit capable of serving 700–1,600 farmers annually, the technology is projected to directly impact over 50,000 farmers within five years, enabling average farmer incomes to rise by 20 – 30% through reduced spoilage and better market access.

The financial model is designed for both sustainability and scalability. A 12m³ cold room unit is projected at ₦5,800,000, while the pilot phase - with a budget of ₦36,355,000 - will deploy three units serving 2,000 – 5,000 farmers. By year five, the scale-up is expected to prevent over 150,000 tons of food loss annually, reduce 50,000–70,000 tons of CO_2-equivalent emissions, and stabilize food prices by improving year-round availability of perishables. A hybrid pay-per-use and direct sales model ensures affordability while guaranteeing long-term financial viability.

This initiative is technically feasible, financially viable, and socially transformative. It directly aligns with Nigeria's Renewed Hope Agenda on food security and with NASENI's mandate to advance indigenous technology development. By reducing waste, cutting emissions, boosting farmer livelihoods, and creating green jobs, this project presents funders with a high-impact, low-risk investment opportunity that delivers measurable economic, social, and environmental returns.

Table of Contents

1.0 INTRODUCTION

1.1 Background Information

Food loss during the post-harvest stage remains a critical global challenge, with nearly 30% of food produced worldwide lost or wasted annually. Perishable crops such as fruits, vegetables, dairy, and fish are especially vulnerable, requiring reliable cold storage and handling systems to maintain quality. These inefficiencies not only erode food security and agricultural profitability but also contribute to climate change, accounting for an estimated 4% of global greenhouse gas emissions. The burden is disproportionately borne by developing regions such as sub-Saharan Africa, where weak infrastructure and limited access to reliable electricity exacerbate the problem.

Nigeria exemplifies this challenge. Despite its position as a leading agricultural producer, the country loses an estimated 40–50% of perishable crops annually, primarily due to inadequate cold storage facilities and unreliable power supply. Rural communities - where electricity access falls as low as 55% - are particularly affected, leading to an estimated 25% income loss for Nigeria's 93 million smallholder farmers. The consequences are severe: persistent food insecurity, volatile food prices, and heightened environmental impact from decomposed produce. Existing cold storage options are often concentrated in urban areas and powered by costly, carbon-intensive diesel generators, making them both inaccessible and unsustainable for the farmers who need them most.

Innovative cold storage technologies offer a transformative pathway to address this systemic gap. Solar-powered, modular, and locally fabricated cold storage solutions provide an affordable, scalable, and eco-friendly alternative tailored for rural communities. By integrating renewable energy, advanced thermal storage, and IoT-enabled monitoring, these systems create a resilient post-harvest infrastructure that preserves food quality, reduces waste, and empowers farmers. Beyond mitigating losses, such solutions open new income streams, create jobs, and support the rise of "agripreneurs" driving inclusive economic growth. Investment in these technologies not only strengthens Nigeria's food system resilience but also delivers measurable social, economic, and environmental returns—aligning with global commitments to food security, sustainable agriculture, and climate action

1.2 Aim and Objectives

The primary aim of this project is to design, fabricate, and commercialize smart solar-powered cold storage units to establish a sustainable post-harvest management system in Nigeria.

The specific objectives are:

(i) Design and fabricate modular, low-cost solar-powered cold storage units that are scalable for community, cooperative, and market-level use.
(ii) Integrate Industry 4.0 technologies, including IoT sensors, remote monitoring dashboards, and predictive analytics, to optimize energy efficiency and manage inventory.
(iii) Reduce post-harvest losses by at least 40% in pilot regions, thereby improving farmer income and enhancing food security.

(iv) Promote local capacity building by sourcing over 70% of structural materials and fabrication processes from Nigerian industries, stimulating local value chains.

(v) Enable commercialization and scalability through cooperative ownership, agro-hubs, and microfinance-supported models to ensure affordability and widespread adoption.

(vi) Contribute to national and global sustainability goals by eliminating reliance on diesel generators, lowering CO_2 and methane emissions, and advancing renewable energy adoption.

1.3 Justification for Project

This project is justified on multiple fronts—economic, social, and environmental—and aligns perfectly with national and institutional priorities.

- Alignment with NASENI's Mandate: Supports NASENI's focus on renewable energy, local manufacturing, and sustainable technology deployment.
- National Development Priorities: Advances Nigeria's Renewed Hope Agenda by reducing food waste, stabilizing prices, and strengthening farmer livelihoods.
- Global Innovation Trends: Aligns with UN SDGs, notably SDG 2 (Zero Hunger), SDG 7 (Clean Energy), SDG 9 (Innovation & Infrastructure), SDG 12 (Responsible Production), and SDG 13 (Climate Action).
- Economic Imperative: Addresses Nigeria's 40% post-harvest loss challenge, unlocking value through higher farmer incomes, job creation in manufacturing and technology, and stimulation of local industries.
- Social Impact: Strengthens rural livelihoods, particularly for women, who manage up to 80% of post-harvest activities, while improving nutrition, raising household incomes, and bridging urban–rural infrastructure gaps.
- Environmental Impact: Provides a clean alternative to diesel-powered cold storage, with the potential to cut over 100,000 tonnes of CO_2 emissions annually by 2030, while reducing methane from food waste and advancing Nigeria's climate commitments.

1.4 Statement of Research/Production Problem

Nigeria faces a critical challenge of inadequate cold storage infrastructure, particularly in rural areas, resulting in annual post-harvest losses of 40–50% of perishable crops. This forces farmers to sell produce immediately at depressed prices, undermines national food security, and contributes to environmental degradation through large-scale spoilage. Existing cold storage solutions, largely diesel-powered, urban-centered, and expensive to operate, are unsuitable for rural communities due to prohibitive costs, fuel supply constraints, and high carbon emissions.

The core research and production problem is to design and manufacture an affordable, accessible, and sustainable cold storage system tailored to off-grid and weak-grid settings. The solution must leverage solar power, locally sourced materials, and smart technologies such as IoT-enabled monitoring to ensure continuous, reliable cooling while reducing operational costs, enhancing farmer incomes, and minimizing environmental impact.

1.5 Scope of Research/Production

The scope of this project covers the entire development lifecycle:

(i) Design & Prototyping: Detailed design of modular cold storage units, integrating solar power systems, Phase Change Material (PCM) thermal storage, and IoT monitoring hardware and software. This includes selecting appropriate components for high-efficiency refrigeration systems with eco-friendly refrigerants.

(ii) Fabrication: Local fabrication of the units, with a target of sourcing over 70% of structural materials from Nigerian industries.

(iii) Testing & Validation: Rigorous laboratory and field testing to ensure technical reliability, safety, and performance efficiency under local operating conditions, including consistent microclimate control and battery reliability.

(iv) Pilot Deployment: Deployment of a limited number of units in selected rural hubs to gather real-world performance data and user feedback.

(v) Refinement & Commercialization Strategy: Based on pilot results, refine the design and develop a comprehensive commercialization strategy for scaled deployment.

2.0 METHODOLOGY

2.1 Materials and Equipment for Production

The proposed project will be a modular, walk-in cold storage unit, scalable for various agricultural applications. The production will require a combination of locally sourced materials and specialised components and designed to maintain a temperature of +2°C to +8°C for perishable agricultural produce:

- **Structural Materials:** Locally sourced mild steel or aluminium for frames; polyurethane foam with galvanized steel/aluminium sheets for insulated panels.
- **Cooling Subsystem:** High-efficiency compressors, condensers, evaporators, and eco-friendly refrigerants. Thermoelectric (Peltier) modules for smaller units.
- **Energy Subsystem:** Locally assembled photovoltaic (PV) panels, MPPT charge controllers, lithium-ion batteries, and DC-AC inverters.
- **Thermal Storage:** Phase Change Material (PCM) blocks to extend cooling capacity during non-solar hours.
- **Smart System:** IoT sensors (temperature, humidity, voltage), GSM/Wi-Fi controllers, and cloud-based platforms for data analytics.
- **Fabrication Equipment:** Welding machines, cutting tools, sheet-metal forming equipment, refrigeration testing tools, and solar PV assembly lines.

2.2 Methods of Production

The production process will follow a structured, phased approach to ensure quality and efficiency:

Phase 1- Concept Validation & Planning: Conduct feasibility studies, market research, and detailed project planning, including budgets and timelines.

Phase 2- Design and Prototyping: Develop detailed blueprints and build initial prototypes to test core functionalities and component integration.

Phase 3- Development and Testing: Fabricate and refine prototypes based on initial feedback. Conduct comprehensive tests for technical reliability, safety, insulation effectiveness, and energy efficiency to meet relevant standards.

Phase 4- Pilot Deployment: Deploy refined units in controlled rural environments (e.g., partner farms or cooperatives) to collect real-world performance data and user feedback.

Phase 5- Refinement & Commercialization Strategy Finalization: Based on pilot results, refine the design, optimize operational parameters, and finalize the commercialization strategy, including business models and financing mechanisms.

Phase 6- Full-Scale Implementation & Roll-Out: Based on pilot results, begin scaled manufacturing and roll out the solution to the target market, supported by training and continuous improvement processes. Incrementally expanding to 180 cold storage systems over four years.

2.3 Graphics/Drawings of Product

Detailed sample of the modular smart solar-powered cold storage unit:

Figure 1: Model of the Solar-Powered Cold Storage

Figure 2: Use of the Cold Storage Unit

2.4 Collaborations for Production

2.4.1 Prototype Production

For the prototype stage, collaboration will be primarily internal and with specialized research partners:

- **Internal Teams:** PEDI’s R&D, engineering (Mechanical, Electrical, ICT), and fabrication teams will lead the design and construction efforts. PEDI possesses technical expertise in these areas, along with fabrication workshops.
- **External Research Partners:** Collaboration with relevant research institutions will be sought for validating PCM performance, IoT system reliability, and advanced control algorithms. Technology suppliers for specialized components will also be engaged.

2.4.2 Commercial Production

For commercial scale-up, partnerships will be expanded to include various stakeholders:

- **Local Fabricators:** Partnering with local fabrication workshops and SMEs to manufacture structural components, stimulating the local economy.

- **Solar Technology Providers:** Collaborating with companies like NASENI Solar Energy Limited for the supply of locally assembled PV panels and components.
- **Financial Institutions:** Working with the Bank of Agriculture, Bank of Industry (BOI), and microfinance banks to develop accessible financing models for end-users.
- **Regulatory Bodies:** Engaging with standards organisations to ensure compliance and certification.
- **Aggregators and Farmer Groups:** Partnerships with agro-cooperatives, farmer associations, and agro-hubs will facilitate bulk adoption and shared ownership models, supporting decentralized storage near production sites.
- **Government and NGOs:** Exploring partnerships for inclusion in constituency projects, women empowerment schemes, and development programs will accelerate deployment and provide crucial support for sustainability.

2.5 Timeline for Production

The project is planned over a 24-month period, divided into key milestones:

- **Months 1–6:** Design, prototyping, and lab-scale validation. This includes concept validation, detailed design, and initial component testing.
- **Months 7–12:** Pilot deployment in selected rural hubs and comprehensive data collection. This phase also includes training and capacity building for SMEs.
- **Months 13–24:** Refinement of the units based on pilot data, finalization of the commercialization strategy, and scaled deployment of over 50 units nationwide. The long-term plan aims to establish 180 units over four years, with an annual target of 20 to 60 new systems.

3.0 COST ANALYSIS

A comprehensive budget breakdown for the pilot phase of this project is provided in the attached "***Detailed Budget Document"***. The pilot, which will deploy three units to serve approximately 2,000 - 5,000 farmers, is estimated at ₦36,355,000. The projected production cost for a single $12m^3$ unit is ₦5,800,000.

This investment translates to a cost of less than ₦7,500 per farmer reached during the pilot and will prevent thousands of tons of food from being lost annually, demonstrating both strong value for money and high social impact.

The major cost categories for the pilot phase include:

1. R&D and Prototyping: Covers design, software development, and initial component testing.
2. Fabrication & Materials: Costs for raw materials (steel, insulation panels), refrigeration components, solar systems, and PCM blocks.
3. Digital Integration: Expenses related to IoT sensors, cloud dashboard development, and AI analytics implementation.
4. Deployment, Training & Pilot Operations: Logistics for transporting units, training farmers, and managing pilot sites.
5. Contingency & Overheads (10%): To cover unforeseen expenses and administrative costs.

Building on this pilot, the overall program aims to scale to 180 units over four years, requiring a total investment of approximately ₦1.044 billion. In the first year, the target is to deploy 20 units at a cost of about ₦116 million. Each $12m^3$ unit will be deployed at ₦5.8 million, ensuring consistent cost efficiency across the scale-up. Funding will be mobilized through institutional support from NASENI, competitive research grants, and partnerships with development agencies and private investors, aligning with Nigeria's push for sustainable, inclusive agricultural transformation.

4.0 MARKETABILITY

4.1 Importance of Project

The project's importance is multi-faceted, addressing critical needs across various sectors in Nigeria:

- Economic: Creates jobs in fabrication and tech services, saves farmers money by cutting post-harvest losses by at least 40%, and stimulates local manufacturing by sourcing over 70% of materials locally.
- Social: Improves quality of life in rural areas by enhancing nutrition and increasing household income. It bridges the urban-rural infrastructure gap and empowers communities through cooperative ownership models.
- Environmental: Promotes sustainability by using renewable solar energy, reducing reliance on fossil fuels. It also curbs methane emissions from food waste, contributing to Nigeria's climate action goals and advancing renewable energy adoption.

4.2 Market Space

The potential market for smart solar-powered cold storage units in Nigeria is both vast and underserved. The agricultural sector continues to face severe post-harvest challenges due to inadequate cold storage infrastructure, compelling farmers to sell produce at low prices during peak harvests or incur significant losses from spoilage. Existing diesel-powered cold rooms are predominantly urban-based, costly to operate, and environmentally unsustainable, leaving rural producers without viable storage solutions.

The target beneficiaries for these units are diverse and widespread across all six geopolitical zones of Nigeria:

- Smallholder Farmers: Who cultivate less than 2 hectares of land and have limited resources, often losing a significant portion of their harvest to spoilage.
- Agro-cooperatives and Farmer Associations: Seeking to collectively manage post-harvest produce and increase market access for their members.
- Rural Market Traders: Who need reliable storage to preserve perishables and stabilize prices over time.
- Food Processors: Looking for decentralized, sustainable cooling solutions closer to production sites.
- Fisheries Sector: Technology is transferable for fish storage in coastal areas.

Industry estimates indicate that Nigeria’s cold chain market could generate over **₦160 billion annually** if existing infrastructure gaps are addressed. Globally, the solar-powered cold storage market is projected to reach **US$254 billion by 2027**, growing at a 13% CAGR. This underscores the scalability and sustainability of solar-powered cold storage systems, which present a timely, cost-effective solution to Nigeria’s rising demand for innovative agricultural infrastructure.

4.3 Strategy and Collaborations for Marketing

A multi-pronged strategy will be adopted, mirroring successful approaches for new technology adoption in Nigeria to ensure widespread market penetration and sustainability:

1. Partnership with Aggregators: Collaborate with agro-cooperatives, farmer associations, and agro-hubs to facilitate bulk adoption, shared ownership, and efficient utilization of cold storage units.
2. Flexible Financing Models: Develop accessible ownership models, such as pay-per-use (PPU), and partner with microfinance institutions, the Bank of Agriculture, and the Bank of Industry to offer affordable financing schemes that overcome the high upfront cost barrier for smallholder farmers. Chilling-as-a-Service (CaaS) models, like ColdHubs' ₦200 per crate per day, have proven effective in Nigeria.
3. Promotional Campaigns: Increase awareness through demonstrations, agricultural extension services, and testimonials from pilot users to build trust and highlight benefits.
4. Government and NGO Partnerships: Explore partnerships for inclusion in constituency projects, women empowerment schemes, and development programs to accelerate deployment and leverage their reach in rural areas.
5. Robust After-Sales Support: Establish a strong network for installation, maintenance, and technical support, building local capacity for servicing the units.

4.4 SWOT Analysis

Strengths:

- Innovative and Sustainable: Utilizes renewable solar energy and integrates smart Industry 4.0 IoT technology for efficiency and remote management.
- Locally Fabricated: Over 70% local content reduces costs, creates local jobs, stimulates the economy, and ensures the availability of spare parts.
- Scalable and Modular Design: Units can be adapted for individual farmers, small cooperatives, or large agro-hubs, allowing flexible deployment across diverse agricultural settings.
- High Impact: Directly addresses critical challenges of food security, farmer income, and climate change mitigation.
- Proven Concept: Models like ColdHubs in Nigeria have demonstrated success in reducing post-harvest losses and increasing farmer income.

Weaknesses:

- High Upfront Cost: The initial investment (₦5,800,000 per unit, or $35,000 USD per unit) may be a barrier for individual smallholders without robust financing mechanisms. Solar-powered systems can be 30% to 50% more expensive than conventional systems.
- Technology Adoption Curve: Farmers may be reluctant to adopt new, perceived complex technologies, requiring significant awareness and education campaigns.
- Maintenance Needs: Requires trained technicians for the IoT and refrigeration systems, and consistent maintenance practices to ensure longevity and efficiency. There is a lack of skilled manpower and distributors for sustainable energy technologies in their infancy.

- Battery Backup Cost: Stand-alone solar cooling systems are expensive due to large battery backups, which contribute 30-40% of the total cost and need replacement every 3-5 years.

Opportunities:

- Huge Untapped Market: Massive demand for cold storage exists in rural Nigeria, where conventional solutions are inadequate.
- Strong Government Support: Significant alignment with national policies on agriculture, food security, and renewable energy, including NASENI's mandate.
- Growing Tech Ecosystem: Nigeria's expanding digital technology sector can be leveraged for IoT development, enabling advanced control and remote monitoring features.
- Climate Finance: Potential to attract funding from climate-focused investors and development agencies due to the environmental benefits and contribution to SDGs.
- "Chilling as a Service" Models: Innovative business models can overcome affordability issues by offering chilling services rather than direct equipment sales.
- Short Payback Period: Despite high upfront costs, some solar cold storage systems demonstrate a compelling business case with short payback periods (e.g., less than 2 years in some instances), provided farmers have access to financing.

Threats:

- Competition from Existing Alternatives: Entrenched diesel-powered cold rooms, though inefficient and polluting, represent an existing alternative that users may be accustomed to.
- Logistical Challenges: Poor rural infrastructure could complicate transportation, installation, and servicing of units in remote areas.
- Regulatory Hurdles: Potential delays in certification for electrical and IoT components, or changes in policy, could impact deployment.
- End-User Affordability and Scepticism: Even with financing, the final cost to farmers might still be a barrier, and there may be scepticism about the necessity and viability of cold storage.

5.0 CONCLUSION

The Smart Solar-Powered Cold Storage Project offers a transformative, scalable, and sustainable solution to Nigeria's 40–50% post-harvest loss challenge. By leveraging over 70% local content, renewable solar energy, PCM thermal storage, and IoT-enabled monitoring, it delivers a cleaner, affordable alternative to diesel cold rooms while empowering smallholder farmers, boosting food security, stabilizing prices, and cutting emissions. With PEDI's technical expertise and strategic partnerships, the project is ready for prototype deployment and commercialization. With adequate funding support, it has the potential to establish a resilient, inclusive cold chain that drives green growth, strengthens rural livelihoods, and positions Nigeria as a leader in sustainable agricultural innovation.

REFERENCES

Alliance for Food Security Action in Africa (AFSAA). (n.d.). *Solar-powered cold storage systems in Nigeria: Addressing post-harvest losses and food security*.

Amjad, W., Munir, A., Akram, F., Parmar, A., Precoppe, M., Asghar, F., & Mahmood, F. (2023). Decentralized solar-powered cooling systems for fresh fruit and vegetables to reduce post-harvest losses in developing regions: a review. *Clean Energy, 7*(3), 635–653. https://doi.org/10.1093/ce/zkad015

Balana, B. B., Aghadi, C. N., & Ogunniyi, A. I. (2022). Improving livelihoods through postharvest loss management: evidence from Nigeria. *Food Security, 14*(1), 249-265. http://dx.doi.org/10.1007/s12571-021-01196-2

Brandessence Nigeria. (2021, November 23). *How solar-powered cold storage is reducing food waste in Nigeria*.

DATOMS. (n.d.). *Solar-powered hybrid cold storage for farmers | Benefits & guide*.

Devanhaar Technologies. (n.d.). *Normal cold storage and solar cold storage: A comparative analysis*.

Food and Agriculture Organization. (2019). *The state of food and agriculture: Moving forward on food loss and waste reduction*. Rome.

Food and Agriculture Organization. (2021). *A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050*. Nature Food, 2, 494–501. doi:10.1038/s43016-021-00322-9.

Goel, N., & Khiyani, S. (n.d.). *Learning brief: How can increased access to solar cold storage improve efficiency and smallholder income in the banana value chain?* Inficold India Private Limited. https://shellfoundation.org/app/uploads/2022/05/BALAMP1.pdf

Knodt, M., & Kimani, R. (2020, December 21). *Taking cold chains off-grid: How solar powered cold rooms could dramatically reduce food waste in Sub-Saharan Africa*. NextBillion.

Kumar, A., Ganesha, T. B., Mishra, B. P., & Agrawal, S. (2022). Challenges of Agri-Start-Ups in Post-Harvest Cold Storage Technologies. *Indian Journal of Extension Education, 58*(1), 89–92. http://doi.org/10.48165/IJEE.2022.58120

Maximise Market Research Pvt Ltd. (2021). *Global solar powered cold storage market analysis and forecast (2019-2027) by type, by end user and by region*. https://www.maximizemarketresearch.com/market-report/global-solar-powered-cold-storage-market/81127/

Munir, A., Ashraf, T., Amjad, W., Asghar, F., Mahmood, F., & Iqbal, A. (2021). Solar-hybrid cold energy storage system coupled with cooling pads backup: a step towards decentralised storage of perishables. *Energies, 14*(22), 7633.

National Renewable Energy Platform. (2024). *Model business case: Standalone solar cold storage business*.

Ogunjirin, O. C., Jekayinfa, S. O., Olaniran, J. A., Ogunjirin, O. A., Ajiboye, O., & Adebiyi, A. O. (2025). Development of a Mobile Solar-Powered Cooling System to Extend Shelf Life of Jute Leaves. *Journal of Science Innovation and Technology Research, 7*(9). https://doi.org/10.70382/ajsitr.v7i9.029

Oyewole, O. S., Raji, M. A., Kazeem, A. A., Ajao, T. O., Ibitoye, O., Abel, O. O., Solomon-Ibuwunwa, O. M., Famakinwa, J. O., & Adewumi, E. O. (2025). SMART TECHNOLOGICAL INNOVATIONS … Oyewole et al., FJS FUDMA Journal of Sciences (FJS) Vol. 9 No. 6, June, 2025, pp 299 –. *FUDMA Journal of Sciences*, *9*(6).

Puri, M. (2016). *How access to energy can influence food losses: A brief overview*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i6626e/i6626e.pdf

Renewable Energy and Energy Efficiency Partnership. (n.d.). *Solar powered multi-use cold storage in Uganda: Station Energy*. https://www.reeep.org/projects/solar-powered-multi-use-cold-storage-uganda-stat

Rutta, E. W. (2022). Understanding barriers impeding the deployment of solar-powered cold storage technologies for post-harvest tomato losses reduction: insights from small-scale farmers in Tanzania. *Frontiers in Sustainable Food Systems, 6*, 990528. https://doi.org/10.3389/fsufs.2022.990528

Sadiq, S. M., Singh, I. P., Ahmad, M. M., & Sani, B. S. (2025). Cold Storage Solutions to Reduce Post-Harvest Loss: Start-ups for Youth in the Agricultural Supply Chain. *New Countryside*, *4*(2), 37–44. https://doi.org/10.55121/nc.v4i2.453

Takeshima, H., Yamauchi, F., & Bawa, D. (2021). *Solar-powered cold-storages and sustainable food system transformation. Evidence from horticulture markets interventions in northeast Nigeria*. IFPRI Discussion Paper.

Transparency Market Research. (n.d.). *Solar powered cold storage market: Global industry analysis, size, share, growth, trends, and forecast, 2019–2027*. https://www.transparencymarketresearch.com/solar-powered-cold-storage-market.html

UNEP and FAO. (2022). *Sustainable food cold chains: Opportunities, challenges and the way forward*. Nairobi, UNEP and Rome, FAO. https://doi.org/10.4060/cc0923en

World Bank Group. (2019). *Global solar photovoltaic power potential by country: Global photovoltaic power potential by country (English)*. Energy Sector Management Assistance Program (ESMAP). http://documents.worldbank.org/curated/en/466331592817725242/Global-Photovoltaic-Power-Potential-by-Country

Yimere, A. (2023, January 21). *How solar-powered refrigerators could cool down climate change*. Modern Farmer.