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SOLAR-POWERED COLD STORAGE SOLUTION FOR SUSTAINABLE FISH PRESERVATION IN OFF-GRID COMMUNITIES: A CASE STUDY OF KENDU BAY AND SORI BEACHES IN HOMA BAY AND MIGORI COUNTIES, KENYA.

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Abstract

Post-harvest fish losses remain a significant challenge in Sub-Saharan Africa, with nearly half of total fish production wasted due to inadequate preservation infrastructure. In Kenya, small-scale fish traders (SSFT) in off-grid areas such as Kendu Bay and Sori Beaches located in Homa Bay and Migori Counties respectively, experience up to 70% post-harvest losses due to limited refrigeration options and the high cost of ice storage. This study aimed to evaluate the feasibility, economic sustainability, and adoption potential of a solar-powered cold storage system (SPCSS) as the renewable solution to these challenges. Guided by the Technology Acceptance Model, the study employed a mixed-methods approach, incorporating structured interviews and field observations from 70 purposively selected fish traders. Data were analysed using thematic coding and cost-benefit assessment to determine viability. Results indicate that traditional preservation methods significantly reduce profit margins, while renewable-powered alternatives can extend shelf life, reduce waste, and boost earnings. The study recommends targeted support from government agencies, Non-governmental Organizations (NGOs), and private investors to scale solar-powered storage in fishing-dependent, off-grid communities. These findings underscore how clean energy innovations in enhancing food security and economic resilience among small-scale fish value chain actors.

Keywords: *Solar-powered cold storage, post-harvest losses, fish preservation, renewable energy, economic sustainability, off-grid communities.*

Introduction

Fish is globally recognized as a critical component of food and nutrition security, serving as a primary source of animal protein for more than 2.9 billion people worldwide (FAO, 2012). In many low and middle-income countries, particularly in tropical and coastal regions, fish represents one of the most affordable and nutritionally dense sources of protein, essential micronutrients, and fatty acids (Ali et al., 2008; HLPE, 2014). Globally, fish contributes approximately 20% of total animal protein intake, underscoring its central role in dietary diversity, livelihoods, and human health (Bennett et al., 2018; FAO, 2012; FAO, 2020; Golden et al., 2016; Hicks et al., 2019; Kawarazuka & Béné, 2011; Thilsted et al., 2016).

Despite its importance, the global fisheries sector continues to face persistent inefficiencies, particularly in post-harvest handling and preservation. The Food and Agriculture Organization estimates that between 27% and 35% of fish and fish products are lost or wasted globally each year, with significantly higher losses reported in small-scale fisheries operating in developing regions (FAO, 2021). Post-harvest fish losses (PHFL) occur across multiple stages of the fish value chain,

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including handling, storage, transportation, and marketing, and are driven primarily by inadequate cold chain infrastructure, poor hygiene, and exposure to high ambient temperatures (Diei-Ouadi & Mgawe, 2011; Affognon et al., 2015; Gustavsson et al., 2011; Parfitt et al., 2010; Kummu et al., 2012; World Bank, 2017).

In Sub-Saharan Africa, PHFL are particularly severe. Studies estimate that quality-related losses alone can exceed 50–70% in small-scale fisheries, especially in off-grid and rural communities where access to electricity and modern preservation technologies remains limited (FAO, 2021; World Bank, 2020). These losses have profound implications beyond food availability. They directly undermine household incomes, reduce trader profitability, exacerbate gender and youth vulnerabilities within fisheries value chains, and contribute to environmental degradation through waste and unsustainable resource exploitation (Béné et al., 2016; World Bank, 2020; Béné et al., 2015; Allison et al., 2020; Kaminski & Christiaensen, 2014; FAO, 2018).

East Africa's fisheries sector plays a vital role in regional food systems and employment, particularly around major inland water bodies such as Lake Victoria, Lake Turkana, and Lake Tanganyika. Lake Victoria alone supports the livelihoods of more than four million people across Kenya, Uganda, and Tanzania through fishing, processing, and trade. However, the region continues to experience disproportionately high post-harvest losses due to structural deficiencies in cold chain infrastructure and energy access (LVFO, 2019; East African Community, 2023; Heck et al., 2007; Njiru et al., 2008; Geheb et al., 2008; Aura et al., 2020).

In Kenya, the fisheries and aquaculture sector contributes approximately 0.8% to national GDP and directly employs over 500,000 people, while indirectly supporting more than two million individuals along the fish value chain (KNBS, 2022; KMFRI, 2023). Small-scale fish traders (SSFTs), many of whom operate informally at landing beaches, constitute a critical yet vulnerable segment of this value chain. Women and youth dominate post-harvest handling and marketing activities, making PHFL not only an economic issue but also a gendered and social equity concern (Béné et al., 2016; KMFRI, 2023; Weeratunge et al., 2010; Siason et al., 2013; FAO, 2016; McClanahan et al., 2015)

Empirical evidence from Kenya consistently highlights high spoilage rates among SSFTs, particularly in off-grid fishing communities. Ice-based storage remains the most commonly used preservation method, yet it is often expensive, unreliable, and logistically constrained, especially in remote beach settings (FAO, 2021; EPRA, 2022). Traditional preservation methods such as sun-drying, smoking, and salting persist but are highly weather-dependent, labour-intensive, and associated with quality degradation and food safety risks (Diei-Ouadi & Mgawe, 2011).

In counties bordering Lake Victoria, including Homa Bay and Migori, these challenges are especially pronounced. Fishing hubs such as Kendu Bay and Sori Beach serve as major landing and trading points but lack reliable electricity and cold storage facilities. As a result, traders frequently incur significant economic losses, sell fish at distress prices during peak catch periods, or discard spoiled fish, further undermining livelihoods and food security. While existing studies document the scale of PHFL in Kenya, much of the literature remains descriptive, with limited empirical analysis of the economic costs of spoilage and the behavioral factors influencing technology adoption among SSFTs.

This reveals a critical gap in the literature: while post-harvest losses are well documented, there is insufficient empirical evidence linking preservation technologies to trader-level economic outcomes and adoption dynamics, particularly in off-grid fisheries contexts.

In response to energy and preservation challenges, renewable energy-based cold storage technologies, particularly solar-powered cold storage systems; have

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gained increasing attention across agricultural value chains in low and middle-income countries. Solar cold storage has been widely piloted in horticulture, dairy, and vaccine storage, where it has demonstrated significant potential to reduce spoilage, stabilize incomes, and improve market access (Dubey et al., 2018; Coulomb & Dubey, 2019; Reardon et al., 2021; IRENA, 2020; GIZ, 2019; Schmidt et al., 2020; Ondraczek, 2013; Yaqoot et al., 2016).

Within agricultural value chains, studies consistently show that solar-powered cold storage can reduce post-harvest losses by 20–50%, enhance price realization for farmers, and improve resilience to climate variability (World Bank, 2020; Efficiency for Access, 2025). These systems are particularly attractive in off-grid settings because they eliminate reliance on fossil fuels and grid electricity, reduce operating costs over time, and align with climate mitigation and adaptation goals.

However, despite these demonstrated benefits, the application of solar cold storage within fisheries value chains remains under-researched, especially in Africa. Existing fisheries-focused studies largely emphasize technical performance or pilot demonstrations, with limited attention to socio-economic feasibility, trader adoption behavior, financing constraints, and institutional governance models (East African Fisheries Report, 2023). This imbalance has resulted in a narrow evidence base that fails to capture how SSFTs perceive, evaluate, and potentially adopt renewable cold storage technologies in real-world trading environments.

Critically, technology-centered studies often overlook the informal nature of small-scale fisheries, where adoption decisions are shaped not only by technical efficiency but also by affordability, trust, collective use arrangements, and perceived risks. Addressing this gap requires analytical frameworks that integrate both economic outcomes and behavioral determinants of adoption.

To address the observed gap between technological availability and low adoption rates in off-grid fisheries, this study is grounded in the Technology Acceptance Model (TAM) developed by Davis (1989) and later extended by Venkatesh and Davis (2000). TAM posits that an individual's intention to adopt a technology is primarily influenced by three interrelated constructs: perceived usefulness (PU), perceived ease of use (PEU), and behavioral intention (BI). (Venkatesh et al., 2003; Venkatesh et al., 2012; Bagozzi, 2007; Dwivedi et al., 2019; Straub, 2009; Heeks, 2018).

Perceived usefulness refers to the extent to which an individual believes that using a technology will enhance their performance or outcomes. In the context of solar-powered cold storage, PU is reflected in traders' expectations of reduced spoilage, extended shelf life, improved product quality, and increased income stability. Perceived ease of use relates to the degree to which a technology is perceived as effortless to operate and maintain. For SSFTs, PEU encompasses factors such as system simplicity, availability of technical support, training, and maintenance requirements. Behavioral intention represents the trader's willingness and readiness to adopt the technology, shaped by PU and PEU as well as contextual constraints such as cost and access to finance.

TAM is particularly well suited to off-grid fisheries contexts because adoption decisions among SSFTs are rarely driven by technology alone. Instead, they reflect a complex interplay between economic vulnerability, risk perception, collective norms, and institutional trust. By applying TAM, this study explicitly links: Perceived usefulness (PU) to reductions in post-harvest losses and income gains, Perceived ease of use (PEU) to training, system reliability, and maintenance feasibility, and Behavioral intention (BI) to traders' willingness to adopt solar-powered cold storage under supportive conditions.

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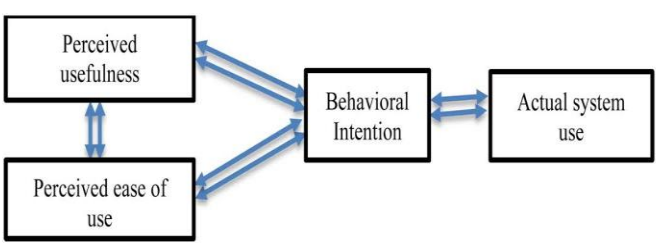
By operationalizing TAM within an off-grid fisheries setting, this study extends its application beyond conventional consumer or organizational contexts and contributes to emerging scholarship on technology adoption in informal, resource-constrained value chains.

Against this backdrop, this study evaluates the feasibility, economic sustainability, and adoption potential of solar-powered cold storage systems among small-scale fish traders in Kendu Bay and Sori Beaches, Kenya. Using a mixed-methods approach, the study integrates quantitative economic analysis with qualitative insights to address three key questions: (1) To what extent can solar-powered cold storage reduce post-harvest fish losses in off-grid communities? (2) What are the economic implications of adopting such systems for small-scale traders? and (3) What factors enable or constrain adoption from a behavioral and institutional perspective?

By bridging empirical evidence on economic losses with behavioral adoption theory, this research contributes to fisheries, renewable energy, and development literature. It provides policy-relevant insights for governments, development partners, and private investors seeking to promote climate-resilient, inclusive, and sustainable cold chain solutions within Kenya's blue economy and comparable fishing-dependent regions across Africa.

Figure 1

Conceptual framework linking Technology Acceptance Model constructs to adoption of solar-powered cold storage systems.



Research Methodology

This study adopted a mixed-methods research design, integrating quantitative and qualitative approaches to comprehensively assess the feasibility, economic sustainability, and adoption potential of Solar-Powered Cold Storage Systems (SPCSS) in off-grid fishing communities. The mixed-methods design was selected to capture both measurable economic outcomes, such as post-harvest losses, spoilage rates, and income variability, and contextual, behavioral insights related to technology perception, trust, and adoption dynamics.

Mixed-methods research is particularly appropriate for complex, community-based studies where technological, economic, and social factors intersect (Creswell, 2014). In the context of small-scale fisheries, adoption decisions are not driven solely by cost-benefit considerations but are also shaped by collective norms, risk perceptions, and institutional constraints. Consistent with Venkatesh and Davis (2000), the integration of qualitative and quantitative methods strengthens explanatory power when evaluating technology adoption under socio-economic uncertainty. The convergent use of multiple data sources enabled triangulation, enhanced internal validity, and improved the robustness of the study's conclusions (Heeks, 2018).

The study was conducted at Kendu Bay Beach in Homa Bay County and Sori Beach in Migori County, both located along the Kenyan shoreline of Lake Victoria. These sites were purposively selected due to their strategic importance as major fish landing and trading hubs within Kenya's Nyanza region and their critical role in the country's blue economy (KMFRI, 2023; LVFO, 2019; KNBS, 2022).

Both Kendu Bay and Sori Beach are characterized by high fishing activity, informal trading structures, and limited access to grid electricity. Preservation practices at these sites are largely constrained to ice-based storage and traditional methods such as sun-drying and

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smoking. Frequent power outages, high ice costs, and inadequate cold chain infrastructure contribute to elevated post-harvest losses. These characteristics make the two sites suitable case studies for evaluating the technical feasibility, economic benefits, and adoption potential of SPCSS in off-grid fisheries contexts.

The target population comprised small-scale fish traders (SSFTs) operating along Lake Victoria who are directly involved in post-harvest handling and marketing activities, including fishmongers, processors, vendors, and transporters. These actors form a critical segment of the fish value chain and bear a disproportionate share of post-harvest losses due to limited access to preservation infrastructure (Béné et al., 2016; FAO, 2021).

The accessible population was drawn specifically from SSFTs operating at Kendu Bay and Sori Beach. These locations were selected based on their high trading volumes, diversity of fish value chain actors, and pronounced preservation challenges.

A total of 70 respondents were selected using purposive sampling, guided by predefined inclusion criteria. Participants were required to: (i) be actively engaged in post-harvest fish handling or trading, (ii) operate at either Kendu Bay or Sori Beach, and (iii) have at least one year of continuous experience in the fish trade.

The final sample comprised 42 respondents from Kendu Bay and 28 from Sori Beach, proportionally reflecting differences in market size and trading intensity. Sample size determination was informed by methodological guidance from Mugenda and Mugenda (2003), who recommend a sample size of 50–100 respondents for exploratory social science studies involving focused and difficult-to-enumerate populations. The selected sample size was considered statistically adequate for generating reliable descriptive and comparative insights, particularly when complemented by qualitative data through triangulation (Israel, 2013).

Demographic diversity was ensured across gender (53% female, 47% male), age (21–60 years), and trading experience (1–15 years), enhancing the representativeness and analytical depth of the study.

Table 1

Demographic Characteristics of Study Participant. Source: Field Data (January-August 2025).

Demographic Variable		Category		Frequency (n=70)	Percentage (%)
		Kendu Bay (n=42)	Sori (n=28)		
Gender	Female	23	14	37	52.9
	Male	19	14	33	47.1
Age Group (Yr.)	21-30	9	6	15	21.4
	31-40	15	10	25	35.7
	41-50	11	7	18	25.7
	51-60	7	5	12	17.2
Experience (Yr.)	1-5	14	8	22	31.4
	6-10	18	12	30	42.9
	11-15	10	8	18	25.7
Location		Kendu Bay		42	60
		Sori		28	40

Structured questionnaires were administered through face-to-face interviews at the study sites. The questionnaires collected quantitative data on respondents' socio-economic characteristics, fish preservation methods, spoilage rates, costs of storage, income variability, awareness of solar cold storage, and

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willingness to adopt SPCSS. Face-to-face administration enabled clarification of questions, probing of responses, and minimization of misinterpretation, particularly in contexts with varying literacy levels (Kothari, 2004; Fowler, 2014).

Direct, non-participant observations were conducted to validate self-reported data and contextualize trading practices. Observations focused on fish handling procedures, storage techniques, hygiene conditions, infrastructure availability, and environmental exposure factors such as heat and transportation delays. These observations provided critical contextual insights that complemented quantitative loss estimates (Yin, 2018; Creswell, 2014).

Respondents were asked to estimate their average daily volume of fish handled, quantities lost to spoilage, and corresponding monetary values over a typical month. These estimates were used to compute post-harvest loss rates and average economic losses per trader. Profit–loss assessments provided an empirical basis for evaluating the economic feasibility and potential benefits of adopting SPCSS (Affognon et al., 2015; World Bank, 2020).

FGDs were conducted to capture collective perceptions, social norms, and shared constraints influencing technology adoption. Five FGDs were held, comprising women fishmongers, male traders and transporters, processors and vendors, youth traders, and mixed stakeholders. Each group consisted of 8–12 participants.

FGDs were essential because adoption of shared infrastructure such as cold storage often depends on collective decision-making, trust, and governance arrangements, which cannot be fully captured through individual interviews. As emphasized by Creswell (2014), FGDs are particularly valuable in technology adoption studies where social influence and peer validation play a significant role. Discussions explored willingness to pay, perceived risks, governance preferences, and expectations regarding SPCSS deployment (Krueger & Casey, 2015; Morgan, 1997).

Table 2

Demographic Characteristics of Study FGD Groups. Source: Field Data (January-August 2025).

FGD Group	Frequency "n"
Women Fishmongers, Kendu Bay.	9
Male Traders & Transporters, Sori.	10
Processors & Vendors, Kendu Bay.	8
Youth Traders, Sori.	11
Mixed Stakeholders.	12
Total	50

Quantitative data were analyzed using Microsoft Excel and Statistical Package for the Social Sciences (SPSS) version 25. Excel was used for data cleaning, organization, and preliminary computations, while SPSS facilitated statistical analysis. These tools were sufficient given the study's exploratory design, sample size, and analytical objectives (Field, 2018; Pallant, 2020).

Descriptive statistics, including means, frequencies, percentages, and cross-tabulations, were generated to summarize demographic characteristics, spoilage rates, and preservation practices. Economic loss analysis was conducted by comparing estimated monthly spoilage quantities against average selling prices.

An independent-samples t-test was employed to compare mean post-harvest loss rates between Kendu Bay and Sori Beach. The t-test was justified because the study sought to determine whether statistically significant differences existed between two independent groups operating in distinct locations. The test assumptions, independence of observations, approximate normality, and comparable variances, were assessed and deemed acceptable for the dataset. Statistical significance was evaluated at $p < 0.05$ (Field, 2018; Pallant, 2020).

Qualitative data from interviews, observations, and FGDs were analyzed thematically using inductive coding. Emerging themes, such as storage challenges,

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technology trust, and financial access barriers; were identified, refined, and used to contextualize and interpret quantitative findings. This integration enhanced explanatory depth and analytical coherence (Braun & Clarke, 2006; Guest, MacQueen, & Namey, 2012).

To enhance validity, the study employed methodological triangulation by integrating multiple data sources and instruments. Questionnaires were pre-tested with five traders and revised to ensure clarity, relevance, and cultural appropriateness. Qualitative findings were cross-validated against quantitative trends to improve interpretive accuracy (Creswell, 2014; Lincoln & Guba, 1985).

Reliability was strengthened through consistency checks across responses and standardized administration of questionnaires. Data collection was conducted by a trained local enumerator fluent in Swahili and local dialects, reducing language-related bias and improving response accuracy.

Ethical standards were strictly observed throughout the study. Participation was voluntary, informed consent was obtained from all respondents, and confidentiality was assured. Participants were informed of the study's purpose, their right to withdraw at any time, and the intended use of the data. No personal identifiers were recorded, and all data were anonymized during analysis (Resnik, 2018; World Medical Association, 2013).

Results and Discussions

The study involved 70 small-scale fish traders (SSFTs) operating at Kendu Bay (n = 42) and Sori Beach (n = 28). The demographic characteristics of respondents are presented in Table 1. Female traders constituted 52.9% (n = 37) of the sample, while males accounted for 47.1% (n = 33). Respondents' ages ranged from 21 to 60 years, with the largest proportion falling within the 31–40 years category (35.7%). Trading experience ranged between 1 and 15 years, with 42.9% reporting 6–10 years of continuous involvement in fish trading.

Fish preservation practices reported by respondents are presented in Figure 2. The majority of traders (74%, n = 52) relied primarily on ice-box storage. Traditional preservation methods such as sun-drying and smoking were used by 15% (n = 11) of respondents, while only 11% (n = 7) reported access to shared refrigeration facilities.

Respondents reported variability in preservation choices based on seasonality, ice availability, and distance to markets. No respondent reported ownership of an individual cold storage unit.

Figure 2

Fish preservation methods used by small-scale traders in Kendu Bay and Sori Beaches.

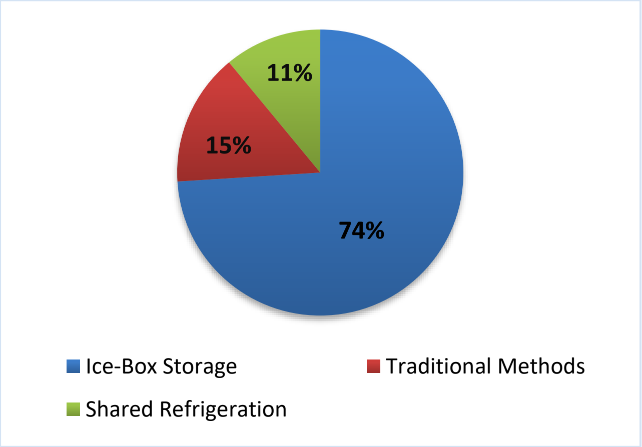

Table 3

Descriptive statistics of post-harvest spoilage and estimated economic losses among small-scale fish traders

Location	Avg. Monthly Spoilage (kg)	Avg. Selling Price (KES/kg)	Estimated Economic Loss (KES)
Kendu Bay	61.2	225	13,770
Sori	52.8	220	11,616
Overall Mean	57.0	222.5	12,693

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Out of the 70 traders surveyed, 89% (n = 62) reported experiencing frequent post-harvest fish losses. The average spoilage rate across both sites was 31.7% of total stock handled per month.

As shown in Table 3, traders operating at Kendu Bay reported a higher mean loss rate (34.1%) compared to those at Sori Beach (28.5%). The estimated average monthly spoilage was 61.2 kg for Kendu Bay and 52.8 kg for Sori. Corresponding estimated monthly economic losses averaged KES 13,770 and KES 11,616, respectively.

An independent-samples t-test indicated a statistically significant difference in post-harvest loss rates between the two sites (t = 2.43, p = 0.017) (Table 4). Comparative economic losses between sites are illustrated in Figure 3.

Table 4

Independent-samples t-test results comparing post-harvest loss rates between Kendu Bay and Sori.

Variable	Group	Mean Loss Rate (%)	Std. Deviation	t-value	p-value
Post-harvest Loss	Kendu Bay	34.1	7.2	2.43	0.017
	Sori	28.5	6.8		

Significant at $p < 0.05$

Figure 3

Comparison of average monthly economic losses between Kendu Bay and Sori Beaches.

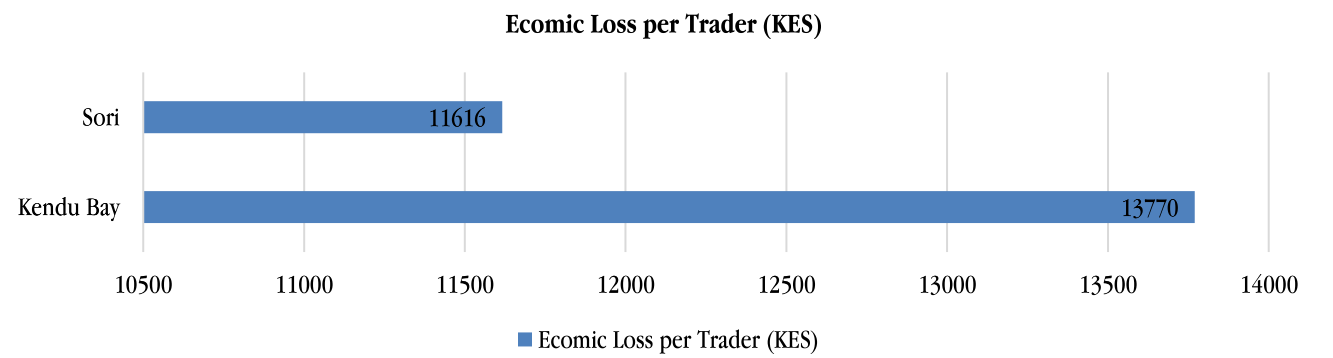
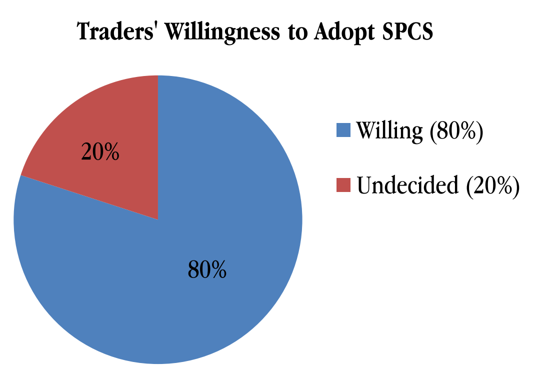


Figure 4

Traders' willingness to adopt solar-powered cold storage systems



Respondents' willingness to adopt solar-powered cold storage systems is summarized in Figure 4. A total of 80% (n = 56) of traders expressed willingness to adopt SPCSS if made available through affordable pricing or cooperative arrangements.

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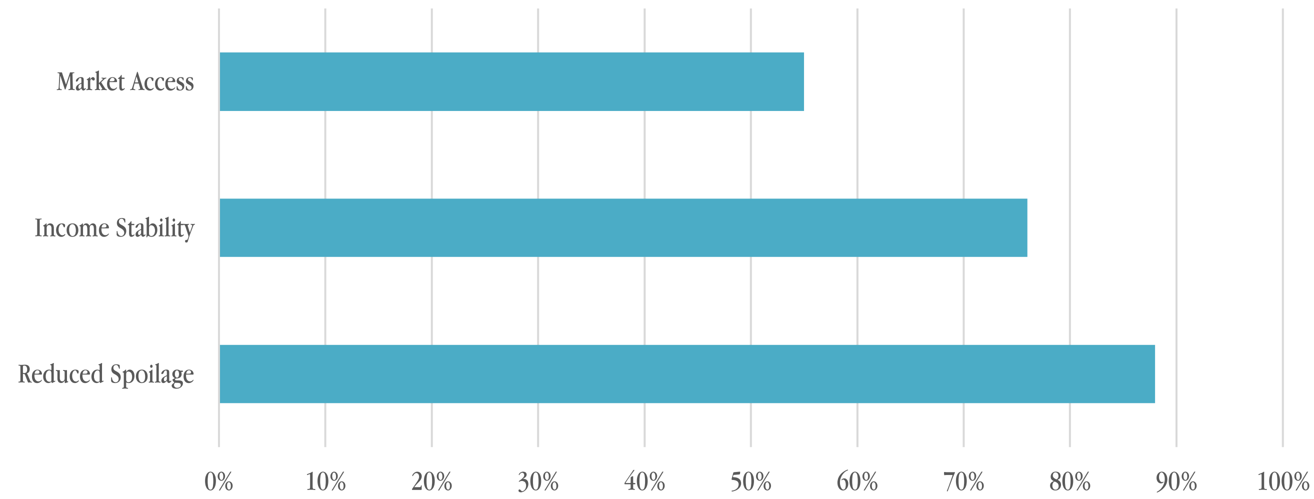
Figure 5

Drivers influencing willingness to adopt solar-powered cold storage systems

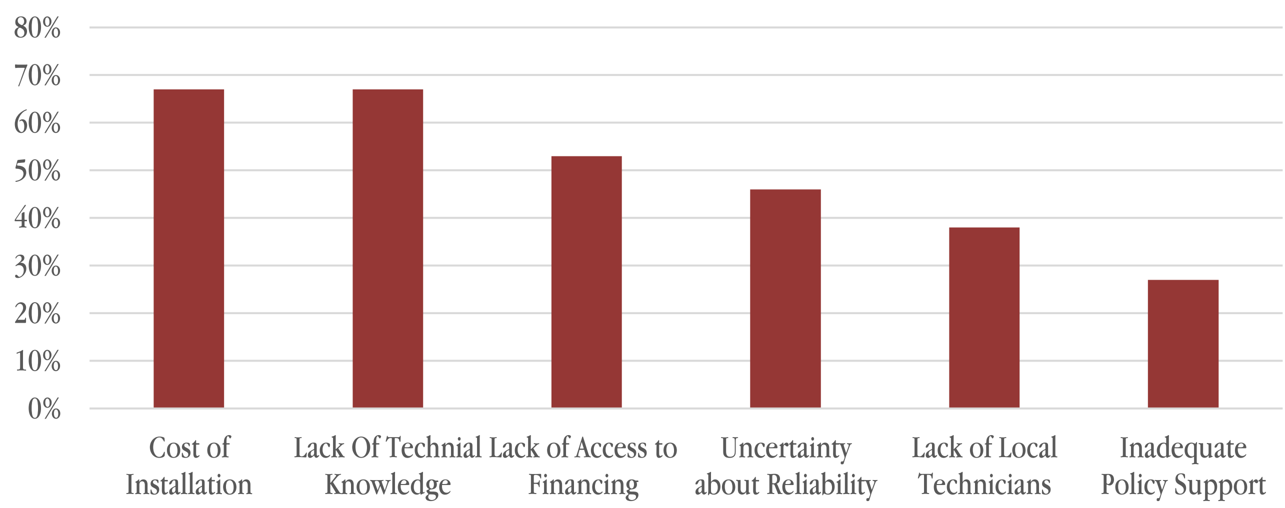


Reported drivers of adoption included expectations of: Reduced spoilage (88%), Improved income stability (76%), and Expanded market access (55%).

Adoption barriers reported by respondents are presented in Figure 6. The most frequently cited barriers were: High installation cost (67%), Limited technical knowledge (54%), and Lack of access to financing (49%).

Figure 6

Reported barriers to adoption of solar-powered cold storage systems



Findings from five FGDs involving 50 participants are summarized in Table 5. Across all groups, participants described experiences related to spoilage frequency, preservation constraints, and awareness of solar cold storage, financing challenges, and governance preferences. Verbatim quotations are presented descriptively to reflect participants' reported experiences without interpretation.

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Table 5

Summary of key themes, subthemes, and illustrative quotations from focus group discussions

FGD Group (n)	Themes	Subthemes	Illustrative Quotes
Women Fishmongers, Kendu Bay (n = 9).	Spoilage & Losses.	High daily spoilage.	"Sometimes I lose up to a quarter of my fish in one day when there is no ice."
	Awareness & Adoption.	Limited awareness of solar cold storage.	"I have only heard of solar fridges in hospitals, but not for fish."
	Gendered Constraints.	Difficulty accessing credit.	"We women traders are not given loans easily. If the cold room is for the group, maybe it can work."
Male Traders & Transporters, Sori (n = 10).	Transport-Related Losses.	Ice dependency & cost.	"From Sori to Kisumu, almost 20% of fish goes bad if ice is not enough."
	Perceptions of SPCSS.	Positive but cautious.	"If there is a solar cold room here, it will reduce our costs. But how will we pay for it?"
	Governance Preference.	Cooperative management.	"The beach management unit can run it, and we pay per use."
Processors & Vendors, Kendu Bay (n = 8).	Reliance on Traditional Methods.	Sun-drying/smoking limitations.	"I dry fish in the sun, but when it rains, the whole stock is wasted."
	Transition to Cold Storage.	Desire to shift if affordable.	"If solar cold storage can keep fish fresh longer, I will stop smoking."
	Cost Concerns.	Fear of unaffordable fees.	"We fear the charges. If it is too expensive, we will still dry the fish."
Youth Traders, Sori (n = 11).	Opportunities & Aspirations.	Expansion potential.	"We young people want to expand, but the business is risky because of spoilage."
	Adoption Readiness.	More open to technology.	"We are more open to new technology than older traders, but we need training."
	Adoption Barriers.	Lack of capital.	"We don't have capital to invest. Maybe donors or government can support."
Mixed Stakeholders (n = 12).	Ownership & Governance.	Community preference.	"For this to succeed, the cold room must be community-owned, not private."
	Sustainability Concerns.	Maintenance & policy needs.	"Solar is good because electricity is unreliable here. But we need training on how to maintain the system."

Three dominant thematic areas emerged across groups: storage challenges, technology trust, and financial access barriers. No differences were observed in thematic categories between Kendu Bay and Sori Beach, although frequency of references varied by group.

The findings indicate that post-harvest fish losses among SSFTs in Kendu Bay and Sori Beach remain substantial, with an average spoilage rate of 31.7% and estimated monthly losses exceeding KES 10,000 per trader. These results are consistent with FAO (2021) estimates that quality-related losses in African small-scale fisheries frequently exceed 30–50%.

Comparable studies in Lake Victoria fisheries in Uganda and Tanzania have reported loss rates ranging between 25% and 45%, attributed to inadequate cold chain infrastructure and high ambient temperatures (Diei-Ouadi & Mgawe, 2011; East African Community, 2023).

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The slightly higher loss rates observed in Kendu Bay may be explained by greater trading volumes and longer transport distances to urban markets, factors previously associated with increased spoilage risk (Affognon et al., 2015; World Bank, 2020).

Economically, these losses represent a significant erosion of trader income and capital accumulation, particularly in an informal sector characterized by low savings and limited access to credit. Similar income suppression effects have been documented among small-scale fish traders in Ghana and Nigeria, where post-harvest losses directly constrained reinvestment and business expansion (Kolding et al., 2014; Béné et al., 2016).

The high reported willingness to adopt SPCSS (80%) contrasts sharply with the absence of existing cold storage ownership among respondents. This gap aligns with the Technology Acceptance Model (TAM), which emphasizes that behavioral intention does not automatically translate into actual adoption in the presence of structural constraints (Davis, 1989; Venkatesh & Davis, 2000).

Perceived usefulness (PU) was strongly reflected in traders' expectations of reduced spoilage and improved income stability, findings consistent with adoption studies in solar-powered cold storage within agricultural value chains (Dubey et al., 2018; Coulomb & Dubey, 2019). However, perceived ease of use (PEU) was moderated by concerns regarding technical knowledge, maintenance capacity, and system reliability, echoing findings from renewable energy adoption studies in rural Africa (Ondraczek, 2013; Yaqoot et al., 2016).

Financial barriers, particularly upfront installation costs; emerged as the dominant constraint, reinforcing evidence that affordability and access to finance are decisive determinants of technology uptake in informal economies (World Bank, 2020; Efficiency for Access, 2025). These findings suggest that adoption of SPCSS is less a function of awareness and more a reflection of institutional and financial accessibility.

The results align with pilot studies in Uganda and Tanzania, where solar-powered cooling systems reduced fish spoilage by 30–45% under cooperative management arrangements (East African Fisheries Report, 2023). Similar outcomes have been observed in India and Bangladesh, where solar cold storage in fisheries improved price realization and reduced distress sales (Dubey et al., 2018; Reardon et al., 2021).

However, unlike studies in horticultural value chains where individual ownership models have shown success, the present findings suggest a stronger preference for community or cooperative-based governance in fisheries contexts. This divergence may be explained by the informal nature of fish trading, income volatility, and collective risk-sharing practices common among SSFTs (Béné et al., 2016; HLPE, 2014).

Beyond economic outcomes, the study highlights important environmental implications. Respondents reported routine disposal of spoiled fish near water bodies and trading sites, contributing to localized pollution and public health risks. Similar environmental externalities have been documented in Lake Victoria and coastal fisheries, where fish waste contributes to water contamination and greenhouse gas emissions (FAO, 2021; United Nations Environment Programme, 2022).

The adoption of SPCSS presents a climate-smart intervention capable of reducing food waste, lowering emissions associated with repeated fishing effort, and minimizing reliance on fossil-fuel-powered refrigeration. These benefits align directly with SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (UN, 2023).

By integrating renewable energy into fisheries preservation, SPCSS offers a pathway toward more resilient, inclusive, and environmentally sustainable blue economy systems, particularly in off-grid communities vulnerable to climate variability.

Conclusions and Recommendations

The findings underscore the critical role of county governments in addressing post-harvest losses within small-scale fisheries. Counties bordering Lake Victoria, such as Homa Bay and Migori, should prioritize the integration of renewable-powered cold storage infrastructure into county-level development plans,

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fisheries strategies, and market infrastructure investments. Given the demonstrated economic losses incurred by traders, county governments can justify targeted subsidies, concessional financing, or public provisioning of shared solar cold storage facilities at major landing sites (World Bank, 2020; FAO, 2021; Kenya Blue Economy Strategy, 2022).

Furthermore, collaboration with Beach Management Units (BMUs) offers a practical governance pathway for managing shared cold storage assets, enhancing accountability, and ensuring equitable access for women and youth traders who dominate post-harvest activities.

At the national level, the results provide empirical support for embedding cold chain development, specifically solar-powered cold storage, within Kenya's Blue Economy Strategy. Post-harvest loss reduction should be treated as core productivity and sustainability intervention rather than a downstream logistical concern. Incorporating SPCSS into blue economy policy frameworks can enhance value retention, reduce resource wastage, and improve income stability across fisheries value chains.

The alignment of SPCSS with climate mitigation and adaptation goals positions it as an eligible intervention for climate finance mechanisms, including climate adaptation funds, green bonds, and results-based financing instruments. Policymakers and development partners can leverage this alignment to mobilize climate finance for cold chain infrastructure that simultaneously addresses food security, renewable energy access, and emissions reduction. Recognizing SPCSS as a climate-smart investment could unlock blended finance models combining public funding, donor support, and private capital (IRENA, 2020; UNEP, 2022; OECD, 2021).

For small-scale fish traders, the findings highlight the tangible economic benefits of improved cold storage access, particularly in reducing spoilage-related income losses and enhancing market flexibility. However, given affordability constraints, individual ownership models may be less viable. Shared-use or pay-per-use models emerge as more practical solutions for traders operating in informal and capital-constrained environments (Béné et al., 2016; HLPE, 2014; Reardon et al., 2021).

The strong preference for cooperative or community-based governance observed among respondents suggests that collective ownership and management models are more likely to succeed in fisheries contexts. Cooperatives, BMUs, and trader associations can play a central role in aggregating demand, managing user fees, and coordinating maintenance of SPCSS infrastructure. Capacity-building efforts targeting these institutions are therefore essential for sustainable operation and long-term adoption.

For private sector actors, including renewable energy firms, cold chain service providers, and impact investors, the study identifies a clear market opportunity within off-grid fisheries. However, commercially viable deployment will require innovative business models tailored to informal markets, such as leasing, service-based provision, or public–private partnerships. Private actors can also collaborate with development agencies to pilot scalable models that balance affordability with cost recovery (World Bank, 2020; Efficiency for Access, 2025).

This study contributes theoretically by extending the Technology Acceptance Model (TAM) into the underexplored context of small-scale fisheries. While TAM has been widely applied in organizational and consumer technology settings, its application in informal, resource-constrained value chains remains limited. The findings demonstrate that perceived usefulness and perceived ease of use remain central to adoption intent, but their influence is strongly mediated by structural constraints such as financing access and collective governance requirements (Davis, 1989; Venkatesh et al., 2012; Dwivedi et al., 2019).

The study also advances understanding of technology adoption in informal economies, where decisions are shaped by collective norms, shared risk, and institutional trust rather than individual optimization alone. This challenges assumptions embedded in conventional adoption models and highlights the need to contextualize behavioral theories within socio-economic realities of informality.

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By empirically linking renewable energy access to food loss reduction and income stability, the study reinforces the energy–food nexus as a critical analytical framework for sustainable development. Solar-powered cold storage emerges not merely as an energy solution but as a systemic intervention capable of transforming food systems, livelihoods, and environmental outcomes simultaneously (FAO, 2018; IRENA, 2020; United Nations, 2023).

While the study provides valuable insights, several limitations should be acknowledged. First, the research was geographically limited to two fishing sites, Kendu Bay and Sori Beach, which may constrain the generalizability of findings to other fisheries contexts in Kenya or beyond. Variations in market structure, species composition, and institutional arrangements may influence outcomes in different locations.

Second, the study employed a cross-sectional design, capturing trader experiences and perceptions at a single point in time. As a result, causal inferences regarding long-term economic impacts and sustained adoption of SPCSS cannot be definitively established.

Third, economic loss estimates were based on self-reported income and spoilage data, which may be subject to recall bias or reporting inaccuracies. Although triangulation and consistency checks were employed to mitigate this limitation, future studies could benefit from longitudinal tracking and objective measurement of spoilage volumes.

Future research should build on these findings in several ways. Longitudinal studies tracking traders over time would provide deeper insights into the sustained economic and behavioral impacts of SPCSS adoption, including changes in income stability, market access, and business growth.

Pilot deployment studies involving real-world installation of solar-powered cold storage systems at landing sites would allow for rigorous evaluation of technical performance, cost-effectiveness, and governance models under operational conditions. Such pilots could also generate evidence for scaling and investment decision-making.

Additionally, future studies should adopt gender-disaggregated and youth-focused adoption models to better understand differentiated impacts and barriers. Given the central role of women and youth in post-harvest fisheries activities, targeted analysis is essential for designing inclusive and equitable cold chain interventions.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The author(s) affirm that no generative AI tools, including platforms such as ChatGPT or similar AI-assisted technologies, were used in the conception, drafting, editing, or refinement of this manuscript. Every section of the paper reflects the independent scholarly effort, critical analysis, and original intellectual contribution of the authors. No part of this work was generated, modified, or influenced by automated tools. The content remains entirely human-written, based on authentic research and academic rigor.

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The author(s) declare no conflict of interest concerning the content, analysis, or outcomes of this research. The study did not promote, evaluate, or receive support from any commercial product, entity, or brand. Its sole objective was to assess the feasibility of solar-powered cold storage for sustainable fish preservation. All data were independently collected and analysed. Participation was voluntary, with no incentives provided. Confidentiality was upheld, and informed consent obtained. This declaration confirms that the authors maintained full professional independence, and the findings are original, unbiased, and free from external or financial influence.

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