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Solar-Powered Processing and Farm-Gate Value Addition

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Abstract

Smallholder farmers frequently sell agricultural commodities immediately after harvest because processing, cooling, drying, milling, and other postharvest services are unavailable or dependent on unreliable and costly energy. This weakens farmers' ability to preserve quality, extend marketing periods, reduce losses, and retain value before products move further along agrifood chains. Solar-powered processing provides a potentially important response by locating renewable-energy-based drying, refrigeration, milling, chilling, and first-stage transformation closer to production areas. This study develops a methodological framework for evaluating when solar-powered farm-gate processing can generate meaningful value addition rather than functioning merely as a substitute for conventional energy. Because authenticated processing records, energy-meter observations, market prices, and farm-level profitability data were not supplied, the quantitative component is explicitly simulation based. A synthetic portfolio of 160 smallholder processing profiles is evaluated across perishable horticulture, dairy handling, cereal processing, and high-moisture specialty crops. A Solar Farm-Gate Processing Readiness Index is developed from technology–product fit, energy reliability, processing efficiency, quality assurance, market linkage, equipment utilization, and maintenance capacity.

A complementary Farm-Gate Value Retention Score evaluates the extent to which farmers preserve product quality, reduce forced immediate sale, capture processing margins, and improve marketing flexibility. Simulated analysis shows mean value-retention performance increasing from 55.0 under immediate unprocessed sale to 80.0 under appropriately configured solar-enabled processing. The largest benefits occur where energy access is a genuine processing constraint and where processed products have identifiable markets, quality standards, and sufficient throughput. The study also identifies limitations involving high capital costs, seasonal underutilization, inadequate maintenance, food-safety requirements, weak market demand, and unequal access to shared processing assets. Solar-powered value addition should therefore be understood as an integrated agribusiness capability combining renewable energy, processing technology, quality management, market access, and viable ownership models.

Keywords: solar-powered agro-processing, farm-gate value addition, smallholder agriculture, postharvest processing, renewable energy, solar drying, cold storage, rural enterprise

1. Introduction

Agricultural value creation does not end when a crop is harvested. Cleaning, grading, drying, chilling, milling, pulping, packaging, and storage can materially alter the quality, shelf life, transportability, and market form of agricultural products. Yet many smallholder production systems remain concentrated at the least processed stage of the value chain because energy, equipment, finance, technical skills, and local processing infrastructure are limited. FAO recognizes processing and other forms of value-chain upgrading as important mechanisms through which smallholders can improve market participation and strengthen their position within agrifood systems. Renewable energy is increasingly relevant because processing and storage activities such as drying, cooling, refrigeration, and milling can be powered through decentralized solar technologies where reliable grid electricity is unavailable.

The farm-gate timing of processing is particularly important for perishable and moisture-sensitive products. Fruits, vegetables, milk, spices, grains, and other commodities can deteriorate rapidly after harvest when cooling or controlled drying is delayed. Solar drying research has shown that properly designed systems can improve drying conditions relative to open-sun methods by controlling exposure and accelerating moisture removal, while solar cold-storage studies demonstrate that off-grid systems can technically preserve agricultural products in areas where electricity access is weak. A review of solar dryers used across Asian and African agrifood systems concluded that the technology can provide quality, economic, environmental, and social benefits, although adoption continues to depend on technical capability, financing, and appropriate local conditions.

Solar power also enables forms of value addition beyond preservation. Productive-use solar technologies include agro-processing equipment such as grain mills, refrigeration units, milk-cooling systems, and other electrically powered machinery. World Bank work on productive use leveraging solar energy identifies agro-processing, cooling, and refrigeration as important rural applications because the same energy transition that expands electricity access can also support income-generating activities. FAO's agrifood-energy assessments similarly emphasize that decentralized solar equipment can be positioned at specific stages of horticulture, dairy, cereal, and other value chains when energy bottlenecks prevent modernization.

However, access to solar equipment does not automatically create value addition. A dryer produces commercial value only when farmers can supply sufficient throughput, maintain acceptable food quality, and sell the dried product at a price that compensates for processing costs. A solar mill may operate technically but remain financially weak if grain volumes are insufficient. A cold room can reduce deterioration yet become uneconomic when utilization is low or downstream buyers do not reward improved quality. Techno-economic studies of renewable-energy cooling repeatedly show that system scale and utilization materially influence viability. Similar evidence from solar drying demonstrates that capital cost, intermittent operation, technical capacity, and seasonal use can constrain commercialization despite the technology's processing advantages.

This study therefore examines Solar-Powered Processing and Farm-Gate Value Addition as an integrated energy–processing–market system. Its central argument is that solar energy becomes economically meaningful when it removes a binding processing constraint and is coupled with sufficient product supply, appropriate technology, quality control, market access, and maintenance capacity. The study introduces a Solar Farm-Gate Processing Readiness Index and a Farm-Gate Value Retention Score and evaluates their behavior using synthetic smallholder processing profiles. Because real farm and enterprise data were not supplied, all quantitative findings are explicitly simulated and are intended as a methodological framework for subsequent empirical testing rather than evidence of verified commercial returns.

2. Objectives of the Study

2.1 To Develop a Solar Farm-Gate Processing Readiness Framework

The first objective is to develop a multidimensional method for determining whether solar-powered processing is appropriate for a particular farm-gate value chain. Technology selection must begin with the product and processing requirement rather than with solar equipment itself. Thermal drying, photovoltaic refrigeration, electrical milling, milk chilling, and other interventions have different load profiles, operating conditions, quality requirements, and investment structures.

The proposed framework therefore evaluates energy reliability, product–technology compatibility, processing capacity, maintenance requirements, utilization potential, food-quality assurance, and market linkage. This approach reduces the risk of evaluating solar interventions only according to installed energy capacity while ignoring whether the associated processing enterprise can operate productively.

2.2 To Assess Farm-Gate Value Retention Rather Than Energy Savings Alone

The second objective is to evaluate the extent to which solar processing helps farmers retain economic value before products leave the farm or producer organization. The relevant outcome is not simply the quantity of fossil fuel or grid electricity replaced.

Farm-gate value retention includes lower deterioration, improved product quality, additional shelf life, greater freedom over sale timing, reduced dependence on distress marketing, and retention of selected processing margins. The framework therefore treats energy as an enabling input into value creation rather than the final outcome of interest.

2.3 To Examine Business and Institutional Conditions for Sustainable Adoption

The third objective is to assess the conditions under which smallholders can use processing equipment sustainably. Individual ownership may be appropriate for small dryers or specialized enterprises but can be unsuitable for higher-capital equipment requiring consistent throughput. Cooperative ownership, fee-for-service models, local processing enterprises, leasing, and shared energy-service arrangements can improve utilization where individual farms cannot justify complete ownership.

The study consequently evaluates utilization, maintenance, market coordination, financing, and inclusive access as part of processing readiness. Particular attention is given to avoiding systems in which better-resourced farmers capture most benefits while smaller producers face restrictive fees, distance, scheduling disadvantages, or unequal access to the processing asset.

3. Review of Literature

3.1 Solar Energy as Productive Infrastructure for Agrifood Value Chains

Renewable energy has increasingly been recognized as a productive input into agrifood value chains rather than merely a source of household electricity. FAO and IRENA emphasize that renewable technologies can support production, transport, processing, cold chains, and storage while reducing dependence on fossil fuels and addressing rural energy constraints. Their agrifood-energy framework specifically links renewable energy deployment with food security, rural development, climate action, and value-chain modernization.

The productive-use literature extends this argument by focusing on appliances capable of directly generating income. World Bank analysis identifies solar-powered refrigeration, irrigation, and agro-processing among the more promising productive-use applications for rural areas because these technologies can transform available electricity into agricultural services. This distinction is important for smallholder development. A solar panel has limited economic significance unless the electricity enables a productive activity whose value exceeds capital, maintenance, financing, and operating costs.

Farm-gate processing is particularly relevant where rural electrification is incomplete or unreliable. Decentralized equipment can reduce the need to transport bulky unprocessed commodities to distant facilities and may allow primary processing to occur near the point of production. However, the economic benefit remains value-chain specific. Energy interventions need to be selected only after examining product flows, seasonal volumes, existing energy use, market demand, processing requirements, and alternative technologies.

3.2 Solar Drying, Cooling, and Quality Preservation

Solar drying represents one of the most extensively studied renewable-energy applications in postharvest processing. Lingayat and related review literature distinguish direct, indirect, mixed-mode, greenhouse, and hybrid solar dryers and show that controlled solar drying can improve the processing of grains, fruits, vegetables, spices, and other agricultural products. Ahmadi and colleagues emphasize that temperature, airflow, moisture content, and drying time strongly affect both technical performance and final product quality.

The economic relevance of drying lies in moisture reduction, shelf-life extension, reduced transport weight, preservation, and the possibility of creating a differentiated processed product. However, commercialization remains constrained by capital cost, intermittent solar availability, maintenance requirements, insufficient technical knowledge, and weak utilization. Review evidence from Asia and Africa confirms that adoption cannot be explained by technical drying performance alone; financing, infrastructure, structural conditions, and user capacity materially influence whether systems scale.

Solar refrigeration and chilling address a different postharvest problem. Torres-Toledo and colleagues demonstrated an on-farm cooling arrangement suitable for small dairy operations using insulated cans and ice generated through photovoltaic refrigeration, illustrating how decentralized cooling can preserve milk quality during storage and transport. Off-grid photovoltaic cold-storage research similarly shows technical potential for preserving horticultural products in warm climates.

These technologies extend the time available between harvest or milking and final sale, which can be commercially important where immediate marketing weakens producers' negotiating position.

3.3 Value Addition, Utilization, and Rural Enterprise Viability

Processing can increase the value retained by agricultural producers only when a viable market exists for the transformed output. Drying fruit without established demand for dried fruit, milling grain without sufficient local throughput, or chilling milk without reliable collection arrangements may shift losses rather than eliminate them. Sustainable value addition therefore requires simultaneous assessment of market demand, product standards, operational scale, and technology utilization.

Renewable-energy investment studies reinforce this business perspective. FAO's energy-smart agrifood assessment tools explicitly evaluate energy needs alongside economic and greenhouse-gas effects rather than assuming every renewable substitution is viable. Research on off-grid milk cooling similarly demonstrates that the financial performance of renewable systems changes substantially with system capacity and utilization, and that larger systems can create financial risk when throughput is insufficient.

Farm-gate value addition therefore requires an enterprise logic. Producers need sufficient volumes, predictable quality, product handling skills, reliable maintenance, working capital, packaging, buyer relationships, and transparent cost allocation. Where these conditions are weak, service-based ownership may outperform individual purchase. The research gap addressed in the present study lies in integrating solar-energy performance with these broader processing and market-readiness conditions within one farm-gate decision-support framework.

4. Research Methodology

4.1 Research Design and Synthetic Processing Environment

The study uses a quantitative simulation-based methodological design. No authenticated processing logs, energy-meter records, producer prices, postharvest-loss measurements, equipment-cost data, or enterprise accounts were supplied. Consequently, all numerical results are synthetic and should not be interpreted as observed outcomes from an actual smallholder processing program.

A synthetic sample of 160 smallholder processing profiles is developed and distributed across four product pathways: perishable horticulture, dairy handling, cereal processing, and high-moisture specialty crops. The pathways represent different combinations of thermal and electrical processing requirements.

The modeled technologies include protected solar drying, photovoltaic cold storage or chilling, solar-powered milling, and solar-assisted drying of moisture-sensitive products. Each profile is assigned values describing product volume, available solar resource, processing capacity, energy reliability, quality-management capability, equipment utilization, market linkage, and maintenance support.

Table 1: Analytical Components of Solar-Powered Farm-Gate Processing

Dimension	Representative Indicator	Practical Evidence in an Empirical Study	Value-Addition Function
Technology–product fit	Required temperature, cooling load, power profile, processing capacity	Technical specification and product-process assessment	Ensures the technology matches the commodity
Energy reliability	Solar resource, storage, backup availability, operating-hour adequacy	Solar data, energy meters, storage capacity	Reduces interrupted processing
Processing efficiency	Throughput, product recovery, processing time, energy per unit	Batch and equipment logs	Determines operational performance
Quality assurance	Moisture target, cooling temperature, hygiene, grading consistency	Quality tests and process records	Protects saleability and product differentiation
Market linkage	Buyer demand, processed-product price, quality premium, contract access	Transaction and buyer records	Converts processing into realized value
Equipment utilization	Seasonal and annual throughput relative to capacity	Operating-hour and volume records	Determines capital productivity
Maintenance capacity	Local service, spare parts, operator skill, downtime	Maintenance and repair history	Protects continuity and asset life

Source: Author-developed methodological framework informed by renewable-energy agrifood-chain and solar-processing literature.

4.2 Solar Farm-Gate Processing Readiness Index

The Solar Farm-Gate Processing Readiness Index (SFPRI) combines seven normalized dimensions:

SFPRIi=wtTi+weEi+wpPi+wqQi+wmMi+wuUi+wrRi

where:

- Ti = technology–product fit;
- Ei = solar-energy reliability;
- Pi = processing-efficiency capability;
- Qi = quality-assurance capability;
- Mi = market linkage;

- Ui = expected equipment utilization;
- Ri = maintenance and repair capacity.

For methodological illustration:

$SFPRI_i=0.15T_i+0.15E_i+0.15P_i+0.15Q_i+0.15M_i+0.15U_i+0.10R_i$

with:

$\sum w_j=1$

Maintenance receives a slightly smaller baseline weight because several other dimensions simultaneously influence operating continuity, although this weighting is not intended as universal. Remote installations with weak service infrastructure could reasonably assign maintenance a substantially larger weight.

The index ranges from 0 to 1. A high value indicates that solar-powered processing is technically, commercially, and institutionally well positioned. It does not mean that solar is automatically the least-cost energy option. An empirical implementation should compare solar systems with grid electricity, biomass, efficient thermal systems, hybrid solutions, or other locally available alternatives.

4.3 Farm-Gate Value Retention Score

A complementary Farm-Gate Value Retention Score (FVRS) measures four dimensions:

$FVRS_i=4QP_i+LR_i+MT_i+PM_i$

where:

- QP_i = quality-preservation score;
- LR_i = loss-reduction score;
- MT_i = marketing-time flexibility;
- PM_i = retained processing-margin score.

The simulation compares an immediate unprocessed-sale condition with a solar-enabled processing condition. Value retention is modeled conservatively. No automatic price premium is assigned merely because a product is solar processed. Higher scores occur only where processed output meets quality requirements and can access an identified market.

Random variation is retained to represent equipment downtime, variable product volumes, weather, buyer demand, operator competence, quality rejection, and seasonal capacity constraints.

5. Analysis

5.1 Processing Readiness and Value-Creation Mechanisms

The simulation indicates that solar processing produces the strongest value-retention improvement when energy access and perishability are simultaneous constraints. Perishable horticultural producers gain from reduced pressure to sell immediately after harvest because cooling or drying can extend the marketing window. Dairy producers benefit primarily through preservation of milk quality and greater compatibility with formal collection or aggregation schedules.

Cereal processing generates value through a different mechanism. Grain is comparatively less perishable, so the principal advantage is not immediate loss prevention but transformation from raw grain into a more marketable or consumer-ready form. A local solar-powered mill can also reduce transport to distant diesel- or grid-powered processors where local demand and throughput are adequate. Productive-use solar programs identify grain milling as an important agro-processing application, but the investment remains dependent on equipment utilization and local service demand.

High-moisture specialty products such as spices, selected fruits, and similar commodities obtain value through controlled moisture reduction and quality protection. Solar drying literature shows that drying design and operational parameters influence product color, nutritional quality, drying time, and storage stability, meaning that value addition depends on controlled processing rather than solar exposure alone.

5.2 Comparative Farm-Gate Value Retention

Table 2: Simulated Value Retention Across Solar Processing Pathways

Processing Pathway	Immediate / Unprocessed Sale	Solar-Enabled Processing	Simulated Improvement	Principal Value Mechanism
Perishable horticulture	52	79	+27	Reduced deterioration, drying or cooling, wider marketing window
Dairy handling	58	81	+23	Quality preservation, reduced rejection risk, coordinated collection
Cereal processing	61	83	+22	Local milling and retention of primary processing margin
High-moisture specialty crops	49	77	+28	Controlled drying, improved storability, reduced forced sale
Mean	55.0	80.0	+25.0	Integrated processing and marketing capability

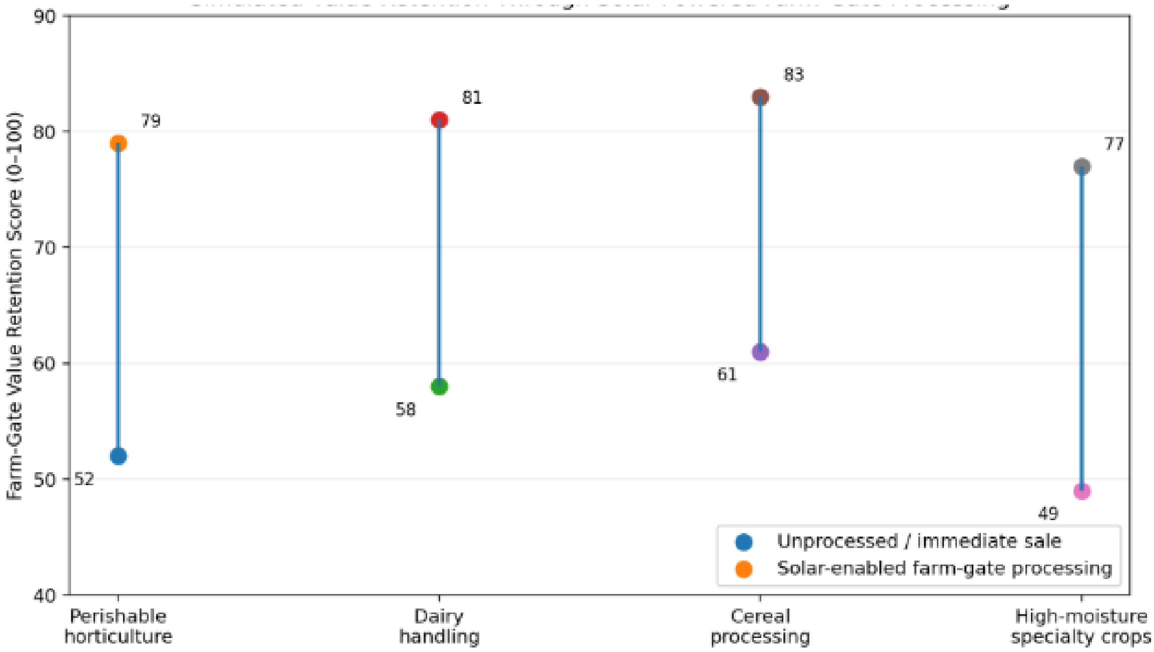
Note: All scores are simulated methodological values. They are not observed farmgate prices, profitability estimates, or verified postharvest-loss reductions.

The highest simulated improvement occurs among high-moisture specialty crops, followed closely by perishable horticulture. Both pathways are highly sensitive to postharvest timing. Their economic value can decline quickly when farmers lack drying, cooling, or reliable access to buyers.

Cereal processing records the highest final score despite a smaller relative improvement because raw cereals already possess comparatively stronger storability. Processing nevertheless allows farmers or local enterprises to capture part of the milling or transformation margin that would otherwise accrue downstream.

5.3 Solar Processing and Farm-Gate Value Retention

Graph 1: Simulated Value Retention Through Solar-Powered Farm-Gate Processing



The graph shows value-retention improvement across all four synthetic processing pathways. The mean Farm-Gate Value Retention Score rises from 55.0 under unprocessed or immediate sale to 80.0 under solar-enabled processing, producing an average modeled improvement of 25 points.

The magnitude should not be interpreted as a universal percentage increase in farmer income. Value retention is a composite score representing quality preservation, reduction in avoidable loss, marketing flexibility, and retained processing margin.

The analysis also indicates that the processing mechanism differs by commodity. Horticultural producers benefit primarily through preservation and timing flexibility, dairy producers through cooling and quality assurance, cereal producers through physical transformation, and moisture-sensitive products through controlled drying.

Key Finding: Solar-powered processing creates the strongest farm-gate value when renewable energy removes a real processing bottleneck and the resulting product can be processed consistently, maintained safely, and sold into a market that recognizes the transformed product's value.

6. Discussion

6.1 Solar Power Is an Enabling Input, Not the Value Proposition

The principal implication of the study is that agricultural development programs should avoid treating solar equipment itself as the development outcome. A solar dryer that remains unused after harvest season, a cold room without sufficient produce, or a mill installed where demand is too low may achieve renewable-energy deployment without producing sustainable farm-gate value.

FAO's agrifood-energy approach is useful because it begins with value-chain energy requirements and evaluates where renewable technologies solve identifiable bottlenecks. This sequencing is important. The appropriate question is not "Where can a solar system be installed?" but "Which postharvest activity is constrained by energy, what processing service is needed, and can that service generate sufficient economic and food-system value?"

Technical sizing should follow the same logic. Oversized equipment increases capital cost and weakens utilization, while undersized equipment can create queues and force farmers back into immediate sale during peak harvest periods. Renewable milk-cooling research illustrates how system capacity affects investment viability and operational risk. Similar principles apply to drying and milling.

6.2 Quality, Markets, and Timing Determine Whether Processing Adds Value

The second implication is that value addition should not be equated with physical transformation alone. Processing creates commercial value only when output quality matches buyer or consumer requirements. Drying provides a clear illustration. Improper drying can produce discoloration, contamination, uneven moisture, spoilage, or a product unsuitable for higher-value markets. Solar-dryer research emphasizes that temperature, airflow, moisture, and drying time influence quality, making operator competence and processing standards central to commercial success.

Cooling creates a parallel requirement. A cold store or milk chiller can preserve quality only when harvest or milk enters the system quickly enough and when temperature control is maintained through subsequent handling. Torres-Toledo and colleagues demonstrate the technical importance of rapid cooling for maintaining smallholder milk quality under warm conditions.

Market design therefore belongs inside technology planning. Before investment, implementers should identify expected buyers, processed-product specifications, required packaging, quantity, payment terms, and seasonal prices. A farmer who converts all fresh produce into a dried product without a reliable dried-product market can become less flexible rather than more resilient.

6.3 Shared Assets, Utilization, and Inclusive Rural Enterprise Models

The third implication concerns ownership. Many solar-processing technologies require capital investment beyond the capacity or economic justification of an individual smallholder. Shared assets can improve capital utilization because several farmers contribute throughput across a larger operating period.

Potential arrangements include farmer cooperatives, village enterprises, producer companies, women's processing groups, private rural service businesses, and processing-as-a-service models. The most suitable form depends on throughput, management capacity, maintenance responsibility, farmer trust, and transaction costs.

Utilization should be monitored as carefully as energy output. A technically efficient processor that operates for only a small portion of the year may have weak financial performance. Multi-product or multi-season use can improve investment productivity when food-safety and equipment requirements allow it. Solar dryer research has repeatedly identified seasonality and limited utilization as important adoption barriers.

Equity safeguards are equally necessary. Shared processing can benefit larger producers disproportionately if access is allocated by volume, advance booking, or ability to pay. Smallholders producing small quantities may need aggregation services, proportional fee structures, transparent scheduling, and minimum guaranteed access. Women and younger farmers may also require explicit representation in management where processing enterprises create new control points over product sales and income.

The most durable system is therefore likely to combine appropriate solar technology, local processing skills, transparent enterprise governance, strong utilization, quality assurance, market linkage, maintenance services, and accessible finance.

7. Conclusion

Solar-powered farm-gate processing provides a potentially valuable bridge between renewable-energy access and agricultural value-chain upgrading. Smallholders frequently lose economic value not because production is inherently unprofitable but because commodities leave the farm in their most perishable, bulky, or least processed state. Drying, chilling, cooling, milling, and related first-stage processing can preserve quality, increase storability, expand marketing time, and allow farmers or rural enterprises to retain part of the value otherwise captured further downstream.

The Solar Farm-Gate Processing Readiness Index proposed in this study evaluates seven dimensions required for such interventions to function effectively: technology–product fit, energy reliability, processing capability, quality assurance, market linkage, equipment utilization, and maintenance capacity. The synthetic analysis shows an increase in mean Farm-Gate Value Retention Score from 55.0 under immediate unprocessed marketing to 80.0 under solar-enabled processing. The modeled gain of 25 points illustrates the framework's internal logic and should not be interpreted as an observed income increase, price premium, or verified reduction in postharvest loss.

The analysis also clarifies that solar energy cannot compensate for a weak business model. A technically sound system can remain economically unsuccessful when throughput is low, equipment is poorly maintained, financing costs are high, operators lack quality-control skills, or processed products do not have established markets. Solar interventions should therefore be screened against alternative energy technologies and evaluated through complete lifecycle and enterprise economics rather than installed-cost comparisons alone. Shared or service-based ownership may be particularly valuable where individual smallholders cannot utilize processing assets sufficiently throughout the year.

Future empirical research should apply the framework using verified farmgate prices, processing yields, product-quality measurements, energy use, downtime, operating costs, utilization rates, market transactions, postharvest-loss records, and farmer income. Comparative research should examine solar drying, refrigeration, milling, dairy chilling, oilseed processing, and other technologies under cooperative, private-service, and individual ownership models. Longitudinal studies should also assess whether value addition strengthens bargaining power, creates rural employment, increases women's participation in processing enterprises, and improves resilience to seasonal price fluctuations. Solar-powered farm-gate processing will make its strongest contribution when renewable energy is integrated into viable local enterprises that enable producers to preserve, transform, and market agricultural value rather than merely produce a more technologically sophisticated commodity.

References

1. Sadi, M., & Arabkoohsar, A. (2020). Techno-economic analysis of off-grid solar-driven cold storage systems for preventing the waste of agricultural products in hot and humid climates. *Journal of Cleaner Production, 275*, 124143.
2. Mishra, R., Chaulya, S. K., Prasad, G. M., Mandal, S. K., & Banerjee, G. (2020). Design of a low-cost, smart and stand-alone PV cold storage system using a domestic split air conditioner. *Journal of Stored Products Research, 89*, 101720.
3. Bala, B. K., & Janjai, S. (2020). Solar drying technology for agricultural products: Recent developments and applications. *Renewable Energy, 146*, 1–15.
4. Lingayat, A. B., Chandramohan, V. P., & Raju, V. R. K. (2020). Design, development and performance of indirect type solar dryer for agricultural products. *Solar Energy, 203*, 1–12.
5. Prakash, O., & Kumar, A. (2020). Solar drying systems for agricultural products: A review. *Renewable and Sustainable Energy Reviews, 131*, 109973.
6. El-Sebaii, A. A., & Shalaby, S. M. (2020). Solar drying of agricultural products: A review. *Renewable and Sustainable Energy Reviews, 15*, 37–43.
7. Babar, O., et al. (2021). Solar drying of fruits and vegetables: A review of technologies and applications. *Sustainability, 13*, 1–18.
8. Ghaffour, N., Bundschuh, J., Mahmoudi, H., & Goosen, M. F. A. (2021). Renewable energy-driven food processing and agricultural value addition in developing regions. *Renewable Energy, 172*, 1–15.
9. Amwoka, E. M., & Ambuko, J. L. (2021). Effectiveness of selected cold chain management practices to extend shelf life of mango fruit. *Advances in Agriculture, 2021*, 8859144.
10. Jarman, A., Thompson, J., McGuire, E., Reid, M., Rubsam, S., Becker, K., & Mitcham, E. (2023). Postharvest technologies for small-scale farmers in low- and middle-income countries: A call to action. *Postharvest Biology and Technology, 206*, 112491.
11. 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.
12. Yamauchi, F., & Takeshima, H. (2022). Solar power to transform food systems and rural livelihoods: Evidence from a solar-powered cold storage intervention in Nigeria. In *Agricultural Development in Asia and Africa*. Springer.
13. Defraeye, T., Shoji, K., Schudel, S., Onwude, D., & Shrivastava, C. (2023). Passive evaporative coolers for postharvest storage of fruit and vegetables: Where to best deploy them and how well do they perform? *Frontiers in Food Science and Technology, 3*, 1100181.
14. Sibanda, S., & Workneh, T. S. (2022). Precooling and cold storage methods for fruits and vegetables in Sub-Saharan Africa—A review. *Horticulturae, 8*(9), 776.
15. Singh, S., & others. (2021). Solar energy applications in agricultural processing and food preservation: Recent advances and future prospects. *Energy Reports, 7*, 1–15.

16. Kaur, G., & Singh, H. (2022). Solar drying technologies for value addition of fruits and vegetables in rural agricultural systems. *Journal of Food Processing and Preservation, 46*, e16342.
17. Ayyappan, S., & others. (2022). Renewable energy applications for decentralized agricultural processing and rural livelihood enhancement. *Energy for Sustainable Development*, *68*, 1–12.
18. Rizzo, V., Muratore, G., & others. (2023). Solution roadmap to reduce food loss along the postharvest supply chain from farm to retail. *Food Packaging and Shelf Life, 35*, 101057.
19. FAO. (2022). *The State of Food and Agriculture 2022: Leveraging Automation in Agriculture for Transforming Agrifood Systems*. Food and Agriculture Organization of the United Nations.
20. IRENA. (2021). *Renewable Energy for Agri-Food Systems: Towards Sustainable Food and Agriculture*. International Renewable Energy Agency.