Clean Energy to Nourish a Continent: Unlocking renewable power for Africa's food systems

January 2026

SNV

gain Global Alliance for Improved Nutrition

PARTNERS IN FOOD SOLUTIONS
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Suggested citation: Partners in Food Solutions, SNV, & GAIN. (2025). *Clean Energy to Nourish a Continent: Unlocking renewable power for Africa's food systems*. White paper.
Authoring organisations: Partners in Food Solutions, SNV, and GAIN.
Research and Technical Support: Earth Partners Ltd.
Cover photo: A young machine operator in a cereal processing plant in East Africa.
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This white paper was commissioned by Partners in Food Solutions, SNV*, and GAIN and prepared with research, technical, and drafting support from Earth Partners Ltd. The authoring organisations extend their sincere gratitude to the funders, partners, and food processors for their generous contribution in making this research possible.
The analysis reflects an independent synthesis of evidence and stakeholder perspectives and should not be interpreted as representing the official views, policies, or positions of the authoring organisations, their governing bodies, partners, or funders.

*Inclusive Markets for Energy Efficiency in Uganda and the Power for Food Partnership

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Abbreviations

AfDB	African Development Bank
AGRA	Alliance for a Green Revolution in Africa
CO_2	Carbon dioxide
DRE	Distributed renewable energy
EE	Energy efficiency
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
FAO	Food and Agriculture Organization of the United Nations
FIT	Feed-in tariff
GHG	Greenhouse gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
LPG	Liquefied petroleum gas
NDC	Nationally determined contribution (under the Paris Agreement)
O&M	Operations and maintenance
PAYG	Pay-as-you-go
PPP	Public–private partnership
PV	Photovoltaic
RE	Renewable energy
ROI	Return on investment
SEC	Specific energy consumption
SME	Small and medium-sized enterprise
UECCC	Uganda Energy Credit Capitalisation Company
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
VAT	Value-added tax
VFD	Variable-frequency drive

List of units

Unit	Description
GJ	Gigajoule (1 GJ = 1,000 MJ)
ha	Hectare (10,000 m^2)
kg	Kilogram
kW	Kilowatt (1,000 watts)
kWh	Kilowatt-hour (3.6 MJ of energy)
kWp	Kilowatt-peak
L	Litre
MJ	Megajoule (1 MJ = 10^6 joules)
MW	Megawatt (1,000 kW)
t	Metric tonne (1,000 kg)
tCO_2e	Tonnes of carbon dioxide equivalent
USD	United States dollar

Glossary

Term	Definition
Agro-processing	The transformation of agricultural products into food, beverages, and industrial raw materials through mechanical, thermal, or biological processes.
Biogas	A renewable fuel produced from the anaerobic digestion of organic matter such as animal manure, crop residues, or food waste; composed mainly of methane and carbon dioxide.
Biomass	Organic material from plants or animals used as a source of energy, including wood, crop residues, and waste products from processing.
Cold chain	A temperature-controlled supply chain used to preserve and extend the shelf life of perishable products such as dairy, meat, fruits, and vegetables.
Energy efficiency (EE)	Using less energy to perform the same task or produce the same output, achieved through improved technology, processes, or practices.
Feed-in tariff (FIT)	A policy mechanism that offers guaranteed payments for renewable electricity fed into the grid.
Hybrid system	An energy system that combines two or more power sources, such as solar PV and diesel generators, to improve reliability and cost-effectiveness.
Net metering	A billing arrangement that credits solar energy system owners for the electricity they add to the grid.
Pay-As-You-Go (PAYG)	A financing model allowing customers to pay for energy equipment in instalments, often through mobile payments.
Photovoltaic (PV)	Technology that converts sunlight directly into electricity using solar cells.
Post-harvest losses	The reduction in quantity and quality of food after harvest but before it reaches the consumer, caused by spoilage, pests, or poor handling and storage.
Renewable energy (RE)	Energy derived from naturally replenishing sources such as sunlight, wind, biomass, water, and geothermal heat.
Specific energy consumption (SEC)	The amount of energy used to produce a unit of product, typically expressed in megajoules per kilogram (MJ/kg) for food processing.
Variable-frequency drive (VFD)	An electronic device that controls the speed and torque of electric motors to match load requirements, improving energy efficiency.
Waste heat recovery	The process of capturing and reusing heat generated as a by-product of industrial processes.

Executive summary

This study on energy efficiency and renewable energy in food processing was commissioned by Partners in Food Solutions (PFS), SNV, and the Global Alliance for Improved Nutrition (GAIN). With a focus on Nigeria and Uganda, the study examines energy use, efficiency gaps, and opportunities for clean energy adoption across Africa's food-processing sector with a nutrition lens.

It also provides actionable recommendations for governments, development partners, and the private sector to support small and medium-sized enterprises' (SMEs) transition to affordable, reliable, and sustainable energy systems—delivering a triple win for nutrition, climate, and economic growth.

The study reveals **high energy costs, uncompetitively high energy intensity, and limitations in current energy mixes**. It addresses a key research gap, providing a multi-country perspective across diverse food value chains. Drawing on a comprehensive literature review, an online survey of 48 processors across more than seven African countries, and six on-site energy audits in Nigeria and Uganda, the analysis combines global-to-African benchmarking with processor-level data and real-world operational insights.

Findings confirm that food processing is the most energy-intensive stage in African agri-food systems, yet it remains inefficient and heavily reliant on diesel generators and biomass. With the right policies, incentives, awareness campaigns, and targeted programmes, modern energy efficiency (EE) and renewable energy (RE) solutions can cut costs, improve reliability, and deliver climate and nutrition co-benefits. The study also highlights gender and inclusion, recognising the specific barriers and opportunities for women-led enterprises in adopting clean energy.

Key messages

- Africa must align clean energy transition with nutrition gains. Food and energy prices are closely linked. Energy inefficiencies in processing raise costs, waste food, and undermine food and nutrition security. Urgent, energy-efficient, and clean energy interventions are needed to improve the availability of nutritious foods and reduce spoilage.
- African food processors are up to two times more energy intensive than their global peers. Outdated equipment, inefficient thermal systems, poor maintenance, and inadequate waste and heat recovery mean that processing one kilogram of produce can require nearly double the energy, reducing competitiveness. Most of the energy demand comes from thermal processes such as drying, frying, pasteurisation, roasting, and boiling, while electricity use peaks in milling, refrigeration, and pumping. Cold chain and refrigeration remain significantly underpowered.
- The processing and post-harvest stages offer a strong renewable energy opportunity. Processing consumes 42% of total energy in food systems and presents the strongest business case. Using RE at this stage provides greater co-benefits, especially in terms of nutritious, perishable foods such as fruits, vegetables, eggs, and dairy, where solar photovoltaic (PV) adoption is already on the rise.
- Energy costs are a major business risk for small and medium-sized enterprise (SME) processors, accounting for 15%–22% of operating expenses. For small processors, even modest bills take a high share of revenue, threatening viability. Thin margins make them highly vulnerable to energy price shocks.
- Grid instability is disruptive and costly. Frequent outages, voltage fluctuations, and poor power quality cause equipment damage, downtime, and significant financial losses. Some processors pay USD 4,800 per year in penalties for poor power factor, while others lose USD 10,000 per year due to harmonics-related trips.

The triple win

Reducing energy intensity and adopting renewable energy in food processing delivers **three interconnected benefits:**

1. **Nutrition:** Minimises post-harvest losses and enhances the affordability and availability of nutritious foods, thereby reducing the risk of malnutrition.
2. **Climate:** Cuts greenhouse gas emissions from diesel and biomass use with clean energy sources. It also strengthens climate resilience by ensuring reliable, low-carbon energy access for rural and peri-urban food systems.
3. **Economic growth:** Boosts the profitability and competitiveness of SMEs, driving inclusive growth and job creation across the agri-food value chain.

- Fossil fuel lock-in undermines Africa's agro-industrialisation and climate mitigation goals. Diesel dominates off-grid processing operations, while unreliable power drives greater diesel dependence. Biomass and firewood account for 18%–48% of fuel use in rural dairy plants and 70%–90% in fish processing, adding to emissions, deforestation, and health risks.

The way forward

- Reducing energy intensity alongside renewable adoption is crucial. Retrofitting with high-efficiency motors, insulated dryers, improved burners, and waste heat recovery could cut specific energy consumption by 25%–40%, reducing both the size and cost of clean energy systems.
- Renewable energy is increasingly viable, with hybrid systems (e.g. solar-diesel, solar-biomass) already achieving 30%–80% diesel displacement in pilot sites. However, return on investment, willingness to pay, and payback periods remain sensitive to seasonality, utilisation rates, and processor size. Whether through standalone solar, hybrid, or grid-optimised efficiency solutions, consistent use also depends on stronger value chains. These include market access for processed goods, reliable offtake to ensure steady demand, and improved storage, handling, and operations. Crucially, consistent renewable energy supply supports nutrient-preserving processing and reliable cold storage, enhancing the availability and quality of perishable, nutrient-rich foods such as dairy, fruits, and vegetables.

Barriers to overcome

- Access to finance, technical skills, and awareness remain the main barriers. Over 70% of surveyed processors reported little or no knowledge of energy-saving or renewable options. Most SMEs cannot self-finance upgrades, and maintenance capacity is limited, especially in rural areas.
- Business viability is another major barrier. SMEs need holistic business support that goes beyond energy solutions. Targeted policy action, blended finance, fiscal incentives, and public-private demonstration projects can accelerate the adoption of clean energy solutions.
- Women-led enterprises face greater barriers to energy transition. They often lack access to finance, information, training, and networks despite dominating certain value chains. Without targeted support, they risk exclusion from clean energy benefits.

Priority intervention opportunities

1. **Energy management and EE retrofits:** Target high-impact processes such as drying, frying, milling, and refrigeration for immediate upgrades using high-efficiency motors, VFD controls, heat recovery units, and insulation to rapidly cut energy costs and prepare for renewable integration. Prioritise nutrient-preserving technologies, including low-temperature drying, controlled frying, and efficient cold chains, to reduce post-harvest nutrient loss while improving food quality and safety.
2. **Hybrid RE systems for reliability:** Promote solar-diesel, solar-grid, and biomass-biofuel-solar hybrids, which combine renewables with backup power. In addition, select energy efficient, nutrition sensitive technology with operational resilience requirements.
3. **Value-chain aggregation and shared infrastructure:** Cooperatives and processor clusters can pool demand for bulk procurement of EE and RE equipment, share pilot facilities for demonstration, and spread operations and maintenance (O&M) costs to overcome scale barriers.
4. **Gender-responsive interventions:** Tailoring finance (micro-leasing, concessional loans, grants), training, and technical support to women-led enterprises could unlock substantial untapped potential in spice, cereal, and small-scale dairy value chains.
5. **Nutrition-sensitive energy interventions:** Integrate nutrition as a performance indicator across all energy initiatives. Promote technologies and business models that enhance nutrient retention, food safety, and access to perishable, nutrient-dense foods. Establish simple nutrition metrics—such as reduction in nutrient loss (%), improved dietary diversity, or increased market availability of fortified or fresh foods. These metrics help track the broader health and food security benefits of renewable and energy-efficient systems.

Actionable recommendations

Policy makers

- Embed agro-processing energy needs in national agriculture, nutrition, and energy strategies.
- Introduce fiscal incentives such as Value Added Tax and duty waivers, and accelerated depreciation for EE and RE equipment.
- Establish Nutrition Energy performance indicators within agro-industrial policy (e.g., post-harvest loss rates, nutrient retention in processed foods, and affordability of nutrient-rich foods).
- Introduce super energy service companies (Super ESCOs) and leverage the energy efficiency networks of agro-processing industries.

Development partners

- Fund RE demonstration hubs, technical training programmes, and subsidised energy audits.
- Integrate renewable energy into programmes targeting agricultural value addition and nutrition-sensitive food systems, such as fortified or perishable food value chains.
- Support blended finance facilities and guarantees to de-risk SME investment, prioritising nutrition-impact enterprises (cold storage, drying of fruits/ vegetables, dairy).
- Promote gender-inclusive access to clean energy financing and training.

Private sector and processors

- Conduct regular energy audits and track specific energy consumption (SEC) alongside nutrition-relevant KPIs, such as nutrient retention.
- Invest in efficient processing systems, VFD-driven or efficient motors, and waste-heat recovery.
- Adopt hybrid RE systems to reduce diesel dependence and improve reliability.
- Participate in peer learning networks and demonstration clusters.

Financial institutions and funders

- Launch dedicated SME energy credit lines and equipment-leasing programmes for EE and RE investments.
- Support aggregation and bulk procurement to reduce unit equipment costs.
- Leverage climate finance for projects delivering measurable emissions reductions (carbon-credit revenues into agribusiness energy upgrades).
- Partner with governments to underwrite risk via credit guarantees.

Mobilising coordinated action

By pursuing these targeted interventions, Africa's food-processing sector can cut energy costs, strengthen climate resilience, and enhance both food security and nutrition outcomes.

Embedding nutrition metrics - such as reductions in post-harvest nutrient loss, improved availability of nutrient-dense foods, and higher dietary diversity scores - within renewable energy and efficiency initiatives ensures that economic and climate gains also translate into better health and well-being.

Major outcome: Specific energy consumption benchmarks

A summary of specific energy consumption by food value chains in Africa is shown in the table below. To ensure comparability across different energy sources (electricity, biomass, biogas) , all reported quantities were converted into common units of measurement, expressed in megajoules (MJ). Standard conversion factors were applied: electricity was converted from kilowatt-hours at a factor of 3.6 MJ/kWh, diesel from litres at 38.6 MJ/litre, and firewood from kilogrammes at 16 MJ/kg. This allowed for the aggregation of diverse fuel types into a single total energy use figure for each processor.

Table 1: SEC in Africa vs. verified global benchmarks (MJ/kg product)

Food value chain	Sub-product	Africa SEC (MJ/kg)	Global SEC (MJ/kg)
Cereals and cereal products	Wheat flour	0.07–0.10	0.05–0.07
	Maize flour	0.12–0.18	0.08–0.12
	Breakfast cereal	11.27	~5.0
	Grain products (general)	4.32–10.8	3.6–7.2
Nuts and seeds	Groundnuts and oilseeds	5.4–9.0	3.6–6.48
	Cashew nuts	13.8	~8–10
Roots and tubers	Cassava *garri*	0.65–1.04	0.43–0.9
	Potato products	~15–20	12–15
Legumes and pulses	Split pulses (*dal*)	0.1–0.3	0.05–0.15
	Canned legumes	2–4	1.5–2.5
Dairy	Liquid milk	0.66–0.70 MJ/L	0.5–0.6 MJ/L
	Yogurt	2.5–3.0	~2.2
	Cheese	~7.7	~8
	Milk powder	2.5	1.3
Fruits	Fruit juice	1–4	1–3
	Fruit concentrate	6–10	5–8
	Jam	5–10	4–8
	Dried fruit	5–12	3–7
Vegetables	Tomato paste	0.34	~0.4
	Mixed vegetables	5–10	4–8
	Frozen vegetables	0.6	0.3–0.5
	Dried vegetables	5–10	3–7
Animal meat, poultry, and eggs	Meat products	3–5	2–4
	Poultry products	0.06–0.17	0.05–0.10
	Dried meat	3–5	2–4
Honey and spices	Honey	3–6	2–4
	Spices	0.5–1.0	0.3–0.6

Source: Author generated *(Best available post-2019 data; African ranges drawn from surveys, audits, and literature).*

1 Introduction

1.1 Energy challenges in Africa's food processing sector

Energy use in food processing accounts for an estimated 40%[1] (Rasul, Bruckner, Mempel, Trsek, and Hertwich, 2024) of the total energy demand across food systems, making it the most energy-intensive stage of the agri-food value chain. This energy supports critical functions such as drying, milling, refrigeration, sterilisation, and packaging—directly shaping product quality, shelf life, and cost competitiveness. Yet in Africa, food processing remains chronically underpowered, undermining both food security and industrialisation goals despite agriculture's role as the backbone of many economies.

Agro-processors across Africa face a trifecta of energy challenges: high and volatile energy costs, unreliable grid electricity, and a heavy dependence on diesel, fuelwood, and other traditional energy sources. Across countries in East and West Africa, biomass remains the primary energy source for approximately 80% of rural households (World Bank, 2025) and even small enterprises commonly rely on firewood, charcoal, or petrol generators. Across rural and peri-urban areas, many small food businesses (especially those run by women) use inefficient equipment and face fuel insecurity, which stifles productivity and profits. A multi-country study (Ampah, Ribeiro, Bugyei, Kumi, and Akowuah, 2021) found that energy can account for 20–50% of operating costs in micro- and small-scale food enterprises—outweighing labour or raw material costs in some cases.

Moreover, in 2023, 565 million people in African countries south of the Sahara lacked access to electricity,[2] a bottleneck that continues to limit on-site value addition and industrial scale-up. Though many larger food processors are connected to the grid, unreliable supply, voltage fluctuations, and prolonged outages pose serious risks. For example, South African manufacturers have faced daily power cuts of 8–16 hours in recent years, prompting multimillion-rand emergency investments in diesel generators and solar power to keep production lines running. In Nigeria, diesel dependence costs the economy over USD 22 billion annually (Energy for Growth Hub, 2025)—a burden disproportionately borne by agro-processing SMEs.

Encouragingly, recent advances in decentralised renewable energy technologies are opening up new opportunities. Solar PV, mini-grids, biomass-powered boilers, and biogas digesters have been deployed across Africa's food sector—with promising results. For instance, solar installations at Nigeria's Premium Poultry Farm will provide over 1 GWh/year of clean power (PRWeb, 2025) halving diesel use. In Kenya, tea factories are using micro-hydro and biomass fuels to cut drying costs, while cold chains in Rwanda and Egypt increasingly leverage solar-powered chilling and ice storage. In South Africa and Morocco, corporate agro-processors are integrating rooftop solar PV and efficient boilers to hedge against grid disruptions and fuel volatility.

Despite these successes, large-scale adoption is hindered by several barriers: capital costs, limited access to credit, technical know-how, and insufficient policy incentives. The majority of Africa's 300 million smallholder farmers and food processors still lack access to the financing or information they need to adopt these innovations (Centre for Strategic and International Studies [CSIS], 2025). Tailored energy strategies that support women-led enterprises, incentivise cleaner fuels, and address seasonal energy variability remain scarce.

Against this backdrop, this energy study maps the current energy landscape in African food processing—focusing on energy intensity, cost pressure, and energy-mix constraints. It emphasises the urgent need to transition towards affordable, reliable, and sustainable energy systems, particularly for SMEs.

1 Global Alliance for the Future of Food, November 2023, *Power shift: Why we need to wean industrial food systems off fossil fuels:* https://futureoffood.org/wp-content/uploads/2023/11/ga_food-energy-nexus_report.pdf

2 International Energy Agency (IEA), International Renewable Energy Agency (IRENA), United Nations Statistics Division (UNSD), World Bank, and World Health Organization (WHO), 2025, Tracking SDG 7: *The energy progress report:* https://iea.blob.core.windows.net/assets/fc78dc81-8167-4c41-b8a6-e3386fecf957/TrackingSDG7TheEnergyProgressReport%2C2025.pdf

The study is structured around four core objectives:

Objective 1:
Energy consumption patterns and point of use.
Quantify how and where energy is consumed across different scales of food processing (small: 1–10 metric tonnes per day; medium: 10–50 metric tonnes per day; large: >50 metric tonnes per day), including variations by product category (staples, dairy, oilseeds). Assess metrics (e.g., kWh/kg processed), major stages of intensity (drying, milling, refrigeration), and operational inefficiencies due to ageing equipment or manual processes. Examine seasonal peaks and the role of power outages and fuel shortages in disrupting operations. Identify where energy disruptions or inefficiencies cause nutrient losses.

Objective 2:
Energy efficiency and renewable energy opportunities.
Evaluate the technical and economic potential of high-efficiency technologies (e.g., advanced dryers, heat recovery) and renewable energy systems (solar PV, hybrid generator sets, biogas, small hydro) for processors across Africa, using case studies in Nigeria, Uganda, and other countries. Identify key adoption barriers, including capital access, awareness, technical capacity, and constraints related to gender roles and access. Examine how efficient and stable energy technologies help preserve micronutrients.

Objective 3:
Feasibility and cost-benefit analysis.
Determine investment feasibility through cost-benefit scenarios, focusing on payback periods, internal rates of return, and maintenance demands. Assess financing instruments (e.g., leasing, pay-as-you-go models, micro-loans) and their impact on adoption. Explore infrastructure constraints like land or roof availability and grid reliability, and whether grid-tied or stand-alone systems are preferred.

Objective 4:
Actionable recommendations.
Translate findings into policy, financial, and partnership frameworks to accelerate clean energy uptake.
Explore how subsidy reforms, tax credits, net metering, and public–private partnerships (PPPs) can catalyse investment. Outline strategies to strengthen capacity building, access to technical services, and inclusive financing for resilient and energy-smart food systems. Provide guidance on policies that link energy reliability with nutrition outcomes—such as supporting energy-smart fortification processes, strengthening cold-chain infrastructure for nutrient preservation, and promoting processing standards that minimise nutrient degradation.

1.2 Purpose of the study

This study on energy efficiency and renewable energy in food processing was commissioned by Partners in Food Solutions (PFS), SNV, and the Global Alliance for Improved Nutrition (GAIN). It aims to comprehensively assess energy consumption patterns across African food processors, focusing specifically on Nigeria and Uganda. The study also identifies opportunities to improve efficiency, evaluates the feasibility of renewable energy integration, and quantifies the potential cost savings and productivity gains that such interventions can bring.

The ultimate goal is to provide actionable recommendations that will enable food processors—especially SMEs—to transition towards affordable, reliable, and sustainable energy systems.

The study maps the current energy landscape in African food processing, highlighting the cost pressures, high energy intensity, and constraints of current energy mixes. It builds on existing literature but fills critical gaps by offering a harmonised, multi-country perspective that cuts across diverse food value chains—something largely missing from previous research.

Uniqueness of this study
While there is a body of literature examining energy use in agriculture and food systems, much of it falls short of addressing Africa's post-harvest and processing energy challenges in a consolidated and sector-wide manner. The distinctiveness of this study lies in:

- **Continental scope and harmonisation:** Most prior studies are geographically limited—focusing on Europe, Latin America, Asia, or the Middle East—and seldom integrate multiple African countries within a single analytical framework. This study takes a pan-African lens, with detailed case analyses from Nigeria and Uganda, to present findings that resonate across the continent.
- **Post-harvest and processing emphasis:** Earlier research often concentrates on crop production stages—from land preparation to harvest—evaluating energy inputs and intensities for specific commodities (e.g., citrus in Türkiye, bananas in India, palm oil in Indonesia). In contrast, this study focuses on post-harvest processing, where energy use is the most intensive and value addition opportunities are greatest.
- **Diverse value chain coverage:** Whereas many studies are confined to a single crop or commodity, this analysis spans nine major food value chains—including staples, dairy, oilseeds, roots and tubers, nuts, animal products, fruits, vegetables, and beverages. This enables cross-comparisons of energy intensity, technology adoption, and renewable integration potential.
- **Integration of field audit data:** Beyond a literature review, this study incorporates on-site energy audits and survey findings from actual food processors. This evidence-based approach moves beyond theoretical estimates to provide grounded and practical insights.
- **Focus on practical applicability:** Rather than being purely academic, the study is designed to support policymakers, industry actors, and development partners in making investment and policy decisions. It also addresses gender and inclusion by recognising the specific barriers and opportunities for women-led enterprises in accessing clean energy solutions.

In summary, this study bridges the gap between global research and African-specific, post-harvest realities—offering a unique, data-driven foundation for accelerating the adoption of energy-efficient and renewable energy solutions in Africa's food processing sector.

1.3 Categorisation of value chains in scope

1.3.1 Food value chains

This study focuses on nine primary categories of food-processing value chains across Africa. The selection reflects both the breadth of agro-industrial activity and the energy intensity of these subsectors, covering staple crops, high-value perishables, and processed food products. These value chains account for a large share of Africa's post-harvest food handling and manufacturing, and they represent critical entry points for improving energy efficiency and integrating renewable energy solutions.

The scope of processed products and final product categories is summarised in Table 2.

Table 2: Food value chain categories, products, and sub-products

Value-chain category	Processed product categories
Cereals and cereal products	Flours, breakfast cereals, baked goods, instant meals, nutrition bars, animal feed, beverages
Starchy roots and tubers	Flours and starches (e.g., potato starch), snacks and crisps, fermented products (e.g., *gari*), animal feed
Beans and legumes	Parboiled beans and legumes, split legumes, pre-cooked products, canned legumes, meal kits, legume flours, legume snacks, dairy alternatives
Dairy	Yoghurt, pasteurised milk, liquid dairy (milk, cream), fermented milk, cheese, butter, spreads, infant formula, whey protein, animal feed
Fruits	Fruit-salad packs, dried or canned fruit, fruit beverages, jams and spreads, fruit syrups, snacks, fruit oils
Vegetables	Ready-to-cook mixes, canned, pickled, dried vegetables, sauces, pastes, and condiments, vegetable beverages
Nuts and seeds	Nut and seed butters, seed oils, snacks (roasted nuts and seeds), plant-based milk alternatives
Animal meat and eggs	Processed meat products (e.g., sausages), canned meat, egg products, animal feed
Honey and spices	Sweeteners (e.g., honey), whole and ground spices, herb and spice-blend formulations

These categories were selected because they represent key agro-industrial sectors with significant energy consumption, established supply chains, and clear opportunities to reduce costs and emissions through energy efficiency and renewable energy adoption.

1.3.2 Categorisation of food processor sizes

For this study, food processors have been classified according to throughput capacity (measured in metric tonnes per day (MTPD) rather than employment size or asset value.

This UNIDO-adapted framework was chosen because energy demand, load profiles, and tariff structures correlate more strongly with production volumes than with other enterprise size metrics.

This size-based categorisation allows for a more accurate estimation of energy intensity, benchmarking against global best practices, and tailoring of energy interventions to processor capacity.

Table 3: Classification of food processors by scale of operation

Sector	Micro (<1 MTPD)	Small (1–5 MTPD)	Medium (5–50 MTPD)	Large (>50 MTPD)
Cereals	Small village mills, hand mills (0.1–0.5 MTPD)[3]	Hammer or plate mills (1–3 MTPD)[2]	Roller flour mills, pasta units (10–30 MTPD)[2, 3]	Industrial mills, automated lines (50–300 MTPD)[2]
Meat[4]	Household slaughter and retail butchers (0.2–0.8 MTPD)[3]	Local abattoirs, informal units (1–3 MTPD)[3]	Regional slaughterhouses with chilling (10–30 MTPD)[3]	Export-grade plants, integrated cold chain (60–200 MTPD)[3]
Poultry and eggs[5]	Backyard slaughter, egg packaging (0.05–0.3 MTPD)[4]	Wet market processors (1–2 MTPD)[4]	De-feathering lines, egg breaking, and drying (10–20 MTPD)[4]	Industrial egg and broiler processors (30–80 MTPD)[4]
Dairy[6]	Hand-milked collection, fermented milk (0.1–0.5 MTPD)[5]	Pasteurisation units (1–3 MTPD)[5]	Yoghurt, cheese lines (5–30 MTPD)[5]	Powdered milk, infant formula, and export dairies (50–200 MTPD)[5]
Fruits and juices[7]	Solar drying, basic pressing (0.1–0.5 MTPD)[6]	Grading and juice pasteurisers (1–5 MTPD)[6]	Pulper, pasteuriser, and filler (10–20 MTPD)[6]	Aseptic filling, multi-fruit plants (50–150 MTPD)[6]
Snacks[8]	Manual frying, roasting (<0.5 MTPD)[7]	Local chip and namkeen makers (1–3 MTPD)[7]	Extruded snack lines, ovens (10–25 MTPD)[7]	Multiline continuous snack systems (40–100 MTPD)[7]
Roots and tubers[9]	Local grating, fermentation (0.2–0.6 MTPD)[8]	Flash dryers, chip lines (1–4 MTPD)[8]	Industrial starch and gari (10–20 MTPD)[8]	Continuous processing and packaging (40–100 MTPD)[8]
Legumes[10]	Sun-drying, pounding (0.1–0.3 MTPD)[9]	Small dehullers, mills (1–3 MTPD)[9]	Canned, pre-cooked legumes (5–25 MTPD)[9]	Multi-product legume lines (40–80 MTPD)[9]

Source: Compiled by the author from literature review

Source note: Table 3 synthesises UNIDO technical manuals (cereal milling, fruit and vegetable, dairy), FAO SME guidelines, and regional studies (e.g., Malabo Montpellier Panel VALUE-UP, TechnoServe SAFE) into a unified throughput-based framework. The breakpoints reflect typical capacity shifts where technology, capital, and market orientation transition from community scale (micro) to regional (medium) to industrial and export-oriented (large) scale. This approach aligns with commonly used methods in agro-industry surveys conducted across countries in West and East Africa, and is widely used for policy and benchmarking.

[3] United Nations Industrial Development Organization (UNIDO), 2010, *Small-scale cereal milling and bakery*: https://www.unido.org/sites/default/files/2009-05/Cereal_milling_01_0.pdf
[4] FAO, 2007, *Meat processing technology for small- to medium-scale producers*: https://openknowledge.fao.org/server/api/core/bitstreams/4cfabbd3-16aa-47f8-ac6f-b54a48cb8abd/content
[5] FAO, 2013, *Poultry Development Review*: https://www.fao.org/4/i3531e/i3531e.pdf
[6] UNIDO, 2019, *Milk and Dairy Products, Post-harvest Losses and Food Safety in* Sub-Saharan Africa: https://www.unido.org/sites/default/files/files/2019-06/Milk_and_Dairy.pdf
[7] UNIDO, 2009, *Small-Scale Fruit and Vegetable Processing*: https://www.unido.org/sites/default/files/2009-04/Fruit_and_veg_processing_01_0.pdf
[8] FAO, 2016, *Good Hygiene Practices in the Manufacture of Fried Snacks*: https://www.fao.org/4/a0740e/a0740e00.pdf
[9] FAO, 1998, *Processing of Roots and Tubers*: https://www.fao.org/4/x5415e/x5415e00.htm
[10] FAO, 2020, *Pulses Processing and Utilization Guide*: https://www.fao.org/4/a1392e/a1392e00.pdf

2 Methodology

This study employed a three-pronged approach—comprising literature review, online surveys, and on-site energy audits—to build a comprehensive understanding of energy use and efficiency opportunities in African food processing. As illustrated in Figure 1, each step provided unique and complementary insights, enabling the research team to progressively refine findings and draw accurate, evidence-based conclusions.

The literature review established a global-to-African baseline, enabling comparisons between African food processing energy use and global benchmarks. The online survey provided primary, processor-level data specific to Africa's context and captured both quantitative and qualitative dimensions. Finally, on-site audits validated the findings through direct measurements of facility-level energy consumption and revealed operational realities no desk-based method could reveal.

2.1 Literature review approach

The literature review gathered, analysed, and synthesised over 200 publications on energy consumption trends, efficiency practices, and renewable energy integration in food processing—focusing on countries in East and West Africa while drawing on relevant global examples. Sources included:

- Peer-reviewed journal articles and academic papers.
- Grey literature, such as energy-audit reports, development project documentation, and sectoral benchmarking studies.
- Industry surveys and statistical databases.

Major repositories included Google Scholar, ScienceDirect, and Academia.edu, with some full-text reports obtained directly from authors where they were not publicly available.

Where gaps existed—particularly for specific African value chains—global data was adapted with caution. The review informed the study's classification of processing scales (micro, small, medium, large), process-flow typologies, and energy-intensity benchmarks for comparison across African processors.

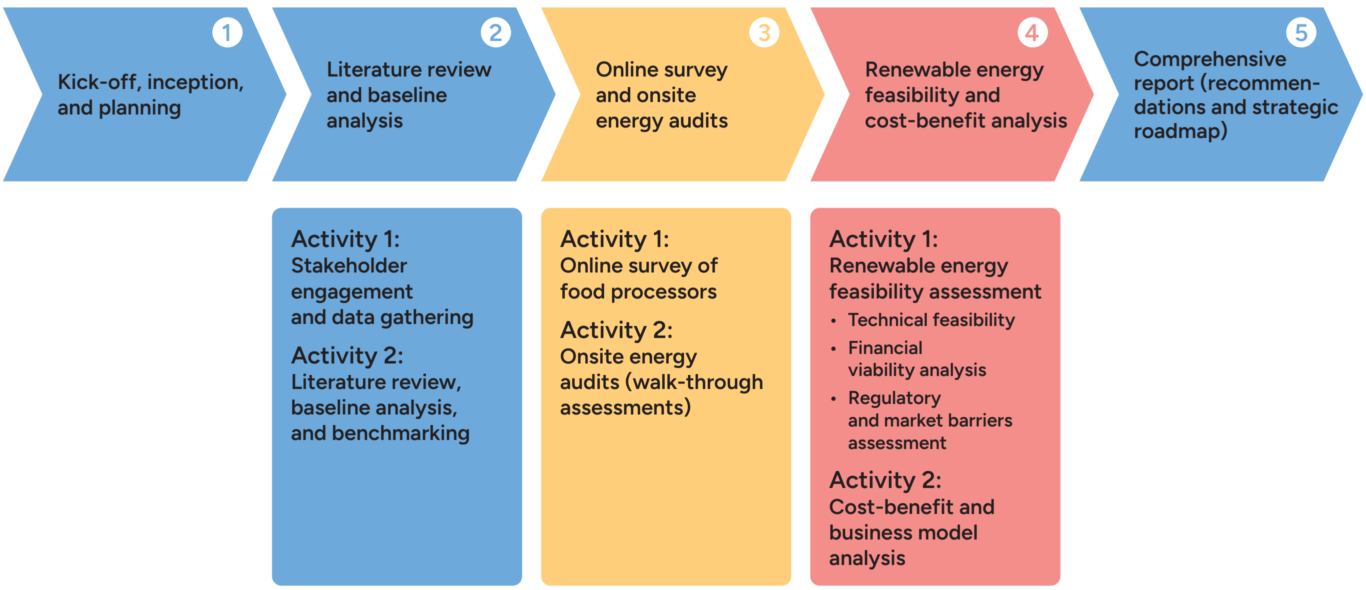
2.2 Energy audit and online survey

A structured online questionnaire, hosted on KoboToolbox, was circulated to over 300 members of the Partners in Food Solutions (PFS) network. It covered a wide range of value chains, including cereals, dairy, snacks, nuts and seeds, fruits, starchy roots and spices, and yielded 48 usable responses from processors across eight African countries.

The survey combined:

- Multiple-choice questions to record primary and secondary energy sources.
- Numeric fields to capture annual consumption (in kWh, litres, or kg) and expenditure (USD).
- Likert scale questions to assess grid reliability, energy challenges, and readiness for investment.
- Open-ended prompts for barriers, ongoing initiatives, and improvement ideas.

Figure 1: Energy efficiency and renewable energy study process



The on-site audits were level 1 walk-through audits with targeted measurements. Six facilities—three in Nigeria[11] and three in Uganda[12]—were selected for detailed study. Audits involved:

- 24–48 hour logging of consumption and peak demand.
- Interviews with energy managers and operators.
- Collection of utility bills, fuel purchase records, and past audit reports.

These audits confirmed survey findings, identified efficiency gaps, and yielded facility-specific recommendations for cost and energy savings.

2.3 Data analysis framework

All data underwent rigorous cleaning for completeness and internal consistency. Outliers beyond three standard deviations from the mean were flagged and verified where possible.

Reported values were standardised into megajoules (MJ) using conversion factors:

- **Electricity:** 3.6 MJ/kWh.
- **Diesel:** 38.6 MJ/litre.
- **Firewood:** 16 MJ/kg.

Incomplete or implausible responses were excluded from analyses requiring those parameters.

Annual energy use was aggregated by source and normalised against production volume to derive specific energy consumption (SEC) in MJ/kg of product. Comparative analysis was carried out by energy source, value chain, and processor scale.

Regional comparisons were treated with caution due to uneven sample distribution.

2.4 Challenges and limitations

While the study's mixed-method approach provided a strong foundation for understanding energy use in African food processing, a number of limitations should be acknowledged. The first relates to gaps in the available literature. For some African value chains, particularly niche commodities, relevant and up-to-date information was scarce. In contrast, cereals such as maize, millet, and wheat were well covered, creating an imbalance in the depth of background information across the different subsectors examined.

The second challenge arose from the survey itself. From over 300 invitations, only 48 usable responses were received, and these varied in completeness. Certain critical fields—such as detailed breakdowns of energy costs by fuel type or production volume—were not always filled in, which reduced the dataset available for some calculations. This also limited the ability to analyse SEC values across the entire sample, as only the companies that provided both production and energy-consumption data could be included.

There was also a noticeable regional skew in the survey responses. More than sixty percent of participating processors were from Nigeria and Uganda, with smaller contributions from Kenya, Ghana, Rwanda, Zambia, Cameroon, and Tanzania. Central and Southern Africa were each represented by only one or two companies. This uneven geographical distribution makes it difficult to draw strong region-to-region comparisons, meaning the findings should be read as indicative rather than definitive for the African sector as a whole.

The on-site energy audits also faced operational constraints. In Uganda, for instance, several audited facilities were not running at full capacity during the assessment period. One egg-processing facility operated only three days per week, requiring the audit team to time their visit to coincide with active production days. Even then, the plant was functioning significantly below its installed capacity. In another case, a grain processor declined the audit altogether because it was out of season and production had ceased. These cases underscore how seasonality strongly affects food processors in Africa, especially small-scale enterprises that depend heavily on raw material availability and market demand.

These limitations show that while the study's findings are grounded in a robust process of literature review, surveys, and audits, they represent a snapshot of the sampled enterprises, rather than an exhaustive portrayal of the sector's full energy landscape.

2.5 Analytical approach

Following the completion of data collection, the research team undertook a structured process to clean, standardise, and analyse the information gathered from the literature review, online survey, and on-site audits. All responses were carefully reviewed for completeness and internal consistency. Entries containing extreme outliers—values falling more than three standard deviations from the mean—were flagged for verification, and in cases where clarification was not possible, such entries were excluded from analyses that depended on those parameters.

[11] AACE Food Processing and Distribution Ltd, Mubadala Rice Mill, Graceco – Food Processing and Manufacturing.

[12] Pristine Foods Limited, Psalms Food Industries Ltd and Maddo Dairies Limited

Rationale for Mega-joule (MJ) as a unit of measurement

To ensure comparability across different energy sources, all reported quantities were converted into common units of measurement, expressed in megajoules (MJ). Standard conversion factors were applied: electricity was converted from kilowatt-hours at a factor of 3.6 MJ/kWh, diesel from litres at 38.6 MJ/litre, and firewood from kilograms at 16 MJ/kg. This allowed for the aggregation of diverse fuel types into a single total energy use figure for each processor.

Annual energy consumption figures were then normalised against annual production volumes to calculate SEC in megajoules per kilogram of product. Production volumes were expressed in metric tonnes per day, enabling classification of processors into four size categories—micro, small, medium, and large—using the UNIDO-adapted framework described earlier in the report.

With the dataset organised in this way, the analysis proceeded to examine patterns of energy use across the nine value chains, looking at variations by processor size, energy source, and product category. Comparative assessments of cost structures were also undertaken to identify the primary drivers of energy expenditure. Where sample sizes permitted, the analysis explored differences between countries and regions, although these findings were interpreted cautiously due to the uneven geographic distribution of the sample.

This systematic analytical framework provided the basis for identifying high-intensity processing stages, the technologies and practices contributing to those intensities, and the points in the value chain where targeted efficiency improvements or renewable energy adoption could deliver the greatest benefits. It also ensured that recommendations emerging from the study were grounded in a consistent, transparent, and replicable methodology, despite the dataset's limitations.

3 Findings of the study

The results presented in this section respond directly to the study's research questions and objectives. For clarity, the findings are organised by food value chain, with each section identifying the primary energy sources reported in both the literature and field data, as well as the main energy-consuming processes within those value chains. Comparisons between African results and global benchmarks are provided later in this section.

3.1 Company size and key metrics

The survey confirms that Africa's food processing sector is dominated by **small and micro enterprises**, with only a minority of firms operating at a medium or large scale. Out of 48 firms surveyed:

- **Micro and small processors (<5 MTPD)** form the sector's backbone. In revenue terms, over half (52%) generate less than **USD 100,000 annually**, while another 31% fall between **USD 100,000 and 500,000**. These include village maize mills, artisanal spice processors, *gari* producers, and local honey enterprises.
- **Medium processors (5–50 MTPD)** comprise about a third of respondents. These firms operate regionally, supplying cereals, dairy, and juice to urban and export markets.
- **Large processors (>50 MTPD)** account for fewer than 20% of firms but command a disproportionate share of production volumes and revenues.

Our **data analysis** highlights that **processor size determines energy burden:**

- **Micro and small firms:** energy represents **20–50% of revenues**; absolute spends are modest (USD 3,000–40,000 per year), but margins are razor-thin.
- **Medium firms:** absolute energy bills (USD 50,000 to 100,000) are higher, but their **energy/revenue ratios fall to 5–12%.**
- **Large firms:** spend >USD 150,000 on energy annually, yet energy accounts for **<10% of revenues** due to scale advantages.

This pattern underscores the **scale trap** in African agro-processing: smaller processors are **least efficient, most exposed to energy costs, and least able to finance efficiency upgrades.**

3.2 Food value chains

The survey covered nine value chain categories (Table 4). **Cereals and cereal products dominate**, with 44% of firms, followed by nuts and seeds (25%), honey and spices (21%), and roots and tubers (21%). Fruits and vegetables account for under one-fifth each, while beans, dairy, and animal products are least represented.

This mirrors regional patterns: **grains and tubers remain the backbone of African diets**, while nuts, spices, and honey serve niche export markets. Dairy and animal protein value chains are less developed, particularly in Uganda and Nigeria, where informal slaughter, milk vending, and egg collection still dominate. These value chains also align with Africa's nutrition challenges—high dependence on cereals limits dietary diversity, while low formalisation in dairy and animal products constrains access to nutrient-rich foods such as calcium, protein, iron, and vitamin B12.

3.3 Single-chain vs. multi-chain operations

Survey findings reveal that African food processors are split between **single-chain specialists** and **multi-chain operators.** This division reflects deeper structural realities such as cereals forming the backbone of processing, diversification as a survival and capacity-optimisation strategy, and informality shaping the way energy is consumed and managed.

Single-chain firms (27 out of 48, or 56%) tend to focus on a single staple or niche product. Cereals and cereal products dominate this group, with 10 firms (37%) engaged primarily in maize flour, rice milling, or sorghum porridge production. Smaller shares occur in dairy, fruits, honey and spices, nuts and seeds, and roots and tubers (each 11%). Vegetables and eggs are represented by one firm each (4%). Notably, no single-chain respondents specialised in animal meat or legumes. These firms benefit from operational simplicity—energy demand is concentrated around a few core processes, such as milling, drying, or chilling—which allows targeted efficiency interventions. For example, maize mills can focus on motor upgrades and solar-diesel hybridisation, while dairy plants can prioritise refrigeration efficiency.

Multi-chain operators (21 out of 48, or 44%) demonstrate a more complex profile. Nearly half of these firms (48%) integrate cereals into their product mix, making them the most common foundation for diversification. Cereals are frequently paired with nuts and seeds (33%), roots and tubers (29%), fruits (24%), or honey and spices (24%). Common combinations include maize milling with groundnut oil extraction; rice and cassava flour under one roof; millet porridge with peanut butter and chilli flakes; and fruit puree alongside flavoured honey. More complex mixes (57% of multi-chain firms) span three or more chains, combining cereals with legumes, vegetables, or animal products. Multi-chain processors contribute to dietary diversity by combining staples with nutrient-dense foods—however, the more complex thermal and refrigeration loads increase risks of nutrient degradation when energy supply is unreliable.

Diversification offers strategic advantages. Firms spread market risk, optimise the use of equipment, and capture higher-value product streams. In contexts like Nigeria and Uganda, where most processors operate informally, diversification is often an adaptive strategy: a maize mill may add groundnut paste or spice grinding to stabilise revenues across seasons. However, this flexibility introduces challenges. Multi-chain firms juggle highly diverse energy requirements—mechanical loads for milling, thermal energy for drying, and refrigeration for fruits and dairy. Balancing these loads under unreliable grid conditions often forces over-reliance on diesel generators, raising SEC to 2–10 MJ/kg compared to <1 MJ/kg in large formal processors. Energy instability in diversified firms directly affects nutrient retention—for example, overheating can reduce vitamin A in oils, poor cold-chain control can reduce vitamin C in fruits, and prolonged storage under fluctuating temperatures can accelerate spoilage of nutrient-rich foods.

This duality highlights a central competitiveness gap. **Single-chain processors** can concentrate on incremental, equipment-specific energy improvements but are vulnerable to market shocks. **Multi-chain processors** gain flexibility and asset utilisation but face higher complexity in energy management. In informal

Table 4: Value chain categories with representative products

Value chain category	Primary products processed	% of total
Cereals and cereal products	Maize flour, rice milling, sorghum porridge	44%
Nuts and seeds	Groundnut paste, sesame oil, almond	25%
Honey and spices	Raw honey, chilli flakes, dried ginger	21%
Starchy roots and tubers	Cassava chips, sweet potato fries, yam flour	21%
Fruits	Juice concentrates, dried mango, fruit purees	19%
Vegetables	Canned tomatoes, vegetable oils, pickled vegetables	10%
Beans and legumes	Cowpea flour, lentil splits, peanut flour	8%
Animal meat and eggs	Processed poultry cuts, egg powder	8%
Dairy	Pasteurised milk, yoghurt, cheese	6%

Source: Survey report (2025). Survey of 48 food processors in Africa.

Table 5: Comparison of single-chain and multi-chain food processors

Processor type	No. of firms (n=48)	Dominant value chains	Typical SEC (MJ/kg)*	Energy/ revenue ratio	Competitiveness implications
Single-chain	27 (56%)	Cereals (37%), dairy, fruits, nuts, roots, and honey (11% each)	0.3–2.5* (milling, dairy, roots); higher (5–8) in small fruit drying	15–30% for micro and small; <10% for larger	Focused operations allow targeted efficiency upgrades (motors, refrigeration) but are vulnerable to market fluctuations
Multi-chain	21 (44%)	Cereals, nuts and seeds (33%), cereals and roots (29%), fruits and spices (24%), complex mixes (57%)	2–10* (combined milling, drying, cold chain)	20–50% for micro and small; 5–15% for medium	Diversification spreads risk and optimises assets, but energy demands are more complex. Informal multi-chain SMEs are often locked in high-SEC traps without financial and technical support

*SEC ranges are based on survey analysis triangulated with FAO (2019), UNIDO (2018), and GAIN (2022).

settings, diversification without access to finance or technical support often results in fragmented operations with high energy costs relative to revenues. For micro and small processors, energy expenditures absorb **20–50%** of revenues, undermining reinvestment capacity. In contrast, medium and large formal processors dilute energy costs to <10% of revenues, capturing economies of scale and competitive advantage. Energy instability in diversified firms directly affects nutrient retention—for example, overheating can reduce vitamin A in oils, poor cold-chain control can reduce vitamin C in fruits, and prolonged storage under fluctuating temperatures can accelerate spoilage of nutrient-rich foods.

Key insights emerge from this analysis:

1. **Cereals as foundation:** Nearly half of all surveyed firms process cereals, and cereals appear in two-thirds of multi-chain cases. Grain milling remains the cornerstone of African food processing.
2. **Diversification as survival:** Multi-chain diversification reflects a strategy to manage market risk and seasonality, especially in informal contexts like Nigeria and Uganda.
3. **Efficiency trade-offs:** Single-chain firms can target narrow efficiency gains, while multi-chain operators need integrated energy management solutions to handle varied load profiles.
4. **Competitiveness risks:** Informality shapes energy use patterns—driving diversification but constraining investment in efficiency upgrades. This leaves SMEs with high SEC, high cost-to-revenue ratios, and limited competitiveness.
5. **Policy relevance:** Supporting SMEs through cooperative models, shared infrastructure, and targeted financing for diversified energy systems could reduce inefficiencies and improve resilience.

3.4 Energy expenditure

Energy remains one of the largest controllable costs for African food processors—second only to raw materials—consistent with findings from FAO (2019) and UNIDO (2020). Survey data across 48 processors show annual energy expenditures ranging from <USD 1,000 to >USD 400,000 per facility, closely linked to processing intensity, plant size, and energy sourcing mix.

Average annual energy expenditure by food value chain was as follows:

- **Vegetables:** ~USD 309,000 per year—highest due to blanching, freezing, and sterilisation operations.
- **Fruits:** ~USD 223,000 per year—driven by juice concentration, pasteurisation, and cold-chain storage.
- **Cereals and cereal products:** ~USD 176,000 per year—dominated by milling, extrusion, and baking.

At the lower end:

- **Starchy roots and tubers:** <USD 5,000 per year—mostly sun-drying, boiling with firewood, or low-intensity peeling.
- **Legume and nut processors:** <USD 10,000 per year—typically de-hulling or oil pressing at low throughput.

These results confirm that **energy expenditure scales non-linearly with throughput and process complexity.** Compared to global benchmarks, African processors operate at a **higher SEC and higher cost per tonne,** driven by high tariffs, diesel dependence, and ageing equipment. Given persistently high rates of micronutrient deficiencies and child stunting across much of Africa, energy-driven processing bottlenecks further compound malnutrition by restricting the supply of safe, nutrient-rich, and fortified foods.

3.4.1 Facility-level findings

Cost trajectories (2022–2024)

Analysis of the three-year dataset reveals **both efficiency-driven cost reductions and capacity-driven cost escalation:**

- **Efficiency successes:**
  - *Tomato Jos Farming and Processing (Nigeria)* cut its energy bill by >50% by switching to grid and efficient pumps, validating IEA findings that pump upgrades can cut farm-processing energy use by 20–30%.
  - *PSALMS Food Industries (Uganda)* reduced energy costs by 80% after piloting solar-diesel hybridisation and rationalising non-core lines.
  - *Sagana Nuts (Kenya)* achieved a 90% reduction by introducing battery storage and load shifting.
- **Expansion and seasonal spikes:**
  - *Neyofoods (Nigeria)* doubled its energy bill (from USD 120,000 to 240,000) during capacity expansion, confirming UNECA's observation that growth without efficiency measures raises energy intensity.
  - *Forest Fruit Foods (Uganda)* and *Bomarts Farms (Ghana)* reported seasonal spikes >40% during harvest-driven fruit drying and juice concentration.

3.4.2 Electricity share bands (OPEX contribution)

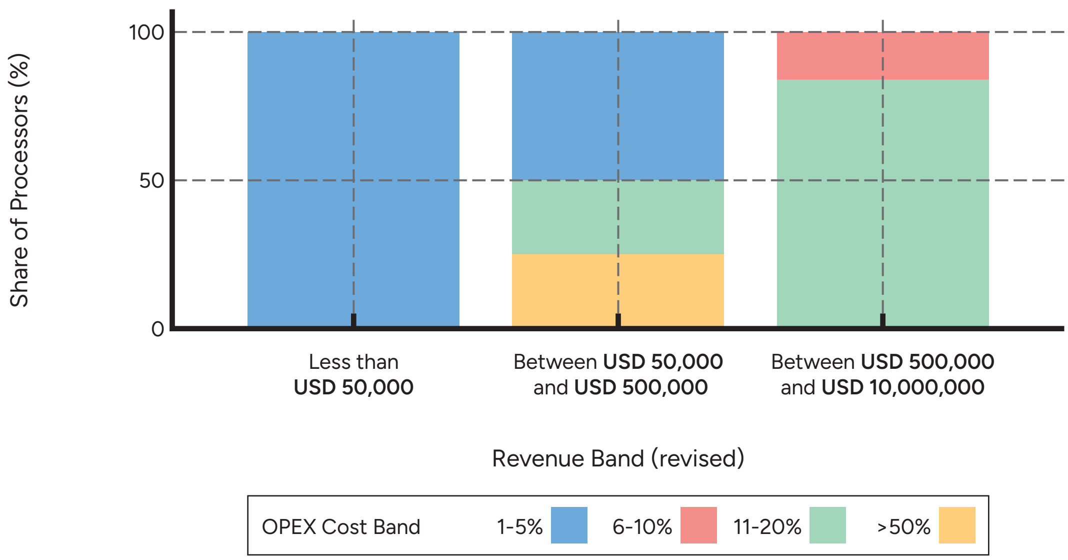
Electricity accounts for **70–97%** of reported energy costs. The distribution by OPEX share band is presented in Table 6.

Figure 2 shows that small processors are widely distributed across cost bands, with a significant share (>20%) experiencing **>50% of OPEX spent on energy.** This puts them in a "survival risk" category.

Table 6: Electricity share bands

Electricity share of OPEX	Processor profile	Implications
Low (<10%)	Large integrated processors (Rabboni, Bomarts, Masaka Creamery)	Manageable exposure—can focus on voluntary decarbonisation and power quality improvement
Moderate (10–20%)	Mid-sized integrated cereal and fruit processors	Requires tariff audits, motor retrofits, and shift optimisation to maintain competitiveness
High (>20%)	Small cereal mills, vegetable processors, honey and spice processors (AgriNet, Neyofoods, Tomato Jos)	Critical cost pressure: concessional financing or RBF incentives are urgently needed

Figure 2: Distribution of energy cost as % of OPEX by revenue category



Source: Author analyses of survey data, 2025.

Interpretation:

- **Large processors (>USD 500k revenue):** 78% fall within the 1–5% OPEX band—energy costs are under control.
- **Small processors (USD 50k to 500k):** Widely spread, with 20% in the >50% OPEX band—highest vulnerability group.
- **Micro processors (<USD 50k):** Polarised group, some are extremely efficient (<5%), others spend >50% of OPEX on energy.

3.4.3 Cost and reliability implications

Energy-related disruptions and poor power quality create both **direct and hidden costs:**

- **Diesel penalty:** Adds 0.4–0.8 MJ/kg to cereal SEC, increasing per-tonne production costs 20–30%.
- **Power factor penalties:** USD 4,000–10,000 per year in fines and equipment downtime (World Bank, 2020).
- **Spoilage losses:** UNEP (2022) estimates 10–15% of perishable products are lost across African countries south of the Sahara due to cold chain interruptions.

3.5 Variation by processor size

Using reported revenue as a proxy for throughput, processors were classified as Micro, Small, Medium, and Large (UNIDO). Table 7 visualises the relationship between annual revenue, annual energy spend, and energy share.

3.6 Cost–effectiveness and financial implications

3.6.1 Unit cost comparison

Our findings confirm global literature that small-scale processors face **10× higher unit energy costs** than industrial-scale plants:

- Hammer mills: USD 22 per tonne vs. USD 2 per tonne for roller mills.
- Small juice processors: USD 280 per tonne vs. USD 75 per tonne in automated plants.

3.6.2 Revenue impact

Energy absorbs:

- For micro processors: **20–50% of revenue**—often unviable.
- For small processors: **15–30%**—constrains reinvestment.
- For large processors: **<10%**—cost is manageable, allowing focus on ESG-driven decarbonisation.

3.6.3 Efficiency investment potential

High-ROI interventions include:

- **Solar PV and storage:** 20–40% diesel displacement, 3–5-year payback.
- **LPG conversion:** Saves USD 120 per tonne, 2–3-year payback.
- **Steam line insulation:** Cuts thermal losses 15–20%, payback <2 years.
- **IE3 motors and VSDs:** Reduce SEC 15–30%, <3-year payback.

Table 7: Comparison of annual energy expenditure, share of revenue and SEC by processor size

Processor size	SEC (MJ/kg)	Annual energy spend (USD)	Energy share of revenue
Micro (<1 MTPD)	0.3–0.4	~3,000	20–50%
Small (1–5 MTPD)	0.4–0.7	25–50k	15–30%
Medium (5–50 MTPD)	0.6–0.8	70–100k	5–12%
Large (>50 MTPD)	>1.0	100k+	<10%

Source: Author analyses from the survey report.

3.6.4 Macroeconomic relevance

Sector-wide adoption of best practices could:

- Save **>20 PJ per year.**
- Avoid **USD 150 M in diesel imports.**
- Reduce **2–5 Mt CO_2e** emissions.

These savings improve **food affordability**, strengthen **export competitiveness**, and free foreign exchange for **reinvestment**.

Implications for energy efficiency financing:
These findings reinforce calls for **dedicated financing windows for SMEs.** Processors in the **>20% OPEX band** should be prioritised for concessional loans, RBF grants, and ESCO-led retrofits. Large processors can be encouraged to adopt **voluntary decarbonisation programmes** and to participate in **carbon credit markets**. Data-driven financing, anchored in SEC reporting, may unlock blended capital and make energy savings bankable.

3.7 Energy cost-effectiveness and policy relevance

3.7.1 Energy cost per unit of product

Converting reported SEC values (MJ/kg) to monetary terms using prevailing electricity and diesel prices reveals substantial disparities between processor sizes and value chains:

Cereals:

- Large roller mills (~0.12 MJ/kg) operate at ~USD 2 per tonne of flour.
- Small hammer mills (~2.0 MJ/kg) face ~USD 22 per tonne—**10× higher cost**, a major competitiveness gap.

Dairy:

- Medium-scale plants (~2.7 MJ/kg) spend USD 80–90 per tonne of milk.
- Large integrated plants (>4.0 MJ/kg due to heavy refrigeration) spend USD 140 per tonne, dominated by chilling and pasteurisation energy.

Fruits and vegetables:

- Medium juice processors (~2.7 MJ/kg) spend USD 75 per tonne.
- Small processors with cold chains (>10 MJ/kg) exceed USD 280 per tonne, often wiping out operating margins.

These findings mirror FAO (2019) and UNIDO (2020) studies, which show that **African processors pay 2–3× more per tonne** than global best practice. This cost differential constrains competitiveness in both domestic and export markets.

3.7.2 Energy burden relative to revenue

Energy burden rises sharply as processor size decreases (see Figure 3):

- **Micro processors (<USD 50k revenue):** 20–50% of annual revenues go to energy.
- **Small processors (USD 50–500k):** 15–30%, with 20% of respondents spending >50% of OPEX on energy—a crisis level that threatens business survival.
- **Medium processors (USD 0.5–5 M):** 5–12% of revenues—closer to global norms but still higher than Asian or European competitors.
- **Large processors (>USD 5 M):** <10%—energy cost is manageable, focus shifts to cost optimisation and carbon footprint reduction.

Interpretation: This pattern is regressive: **the smallest players bear the highest relative energy cost burden**, a key driver of Africa's "missing middle" problem in agro-industrial upgrading (UNECA, 2020). Without intervention, these firms face stagnant growth or market exit, undermining rural job creation and value addition.

3.7.3 Financing implications

These findings have direct implications for energy-efficiency and renewable energy financing in Africa:

1. **Prioritise SMEs:** Processors in the **>20% OPEX band** should be targeted first. Efficiency gains here deliver the highest marginal impact—reducing OPEX burden by 15–25% can mean the difference between survival and exit.
2. **Design blended finance instruments:**
   - **Results-based financing (RBF):** Suitable for solar-diesel hybrid systems and motor retrofits.
   - **Concessional credit lines:** Address CAPEX barriers for energy-efficient boilers, chillers, and steam systems.
   - **ESCO or performance contracts:** Enable pay-as-you-save models for micro and small processors who cannot self-finance upgrades.
3. **Enable data-driven lending:** Energy monitoring (kWh/kg, MJ/tonne) should be incentivised to unlock performance-based lending and carbon-credit aggregation. Donors and DFIs can support **standardised SEC reporting frameworks.**
4. **Reduce diesel dependence:** Hybridisation (PV, storage and generator set) should be a strategic priority, given that diesel costs constitute 100% of energy spend in some value chains (vegetables, cereal-fruit).

3.7.4 Aggregate sector-wide savings potential

If processors across the continent halved SEC (e.g., cereals from 2 MJ/kg to 1 MJ/kg):

- **Over 20 PJ per year** energy saved—equivalent to powering 5 million African households.
- **USD 150 M per year** in diesel imports avoided—improving foreign exchange balance.
- **2–5 Mt CO_2e per year** reduction in emissions—aligning with NDC and net-zero targets.

Such gains could lower processing costs by 10–20%, strengthen food affordability, and increase the competitiveness of African agro-exports (tea, coffee, flour, juice concentrate) in regional and global markets.

3.7.5 Policy and programmatic relevance

The evidence points to three actionable levers for policymakers, donors, and financiers:

1. **Subsidise efficiency investments:** Provide matching grants or tax rebates for energy audits, IE3 motors, insulation, and hybrid systems.
2. **Strengthen tariff and power-quality regulation:** Lower off-peak tariffs and penalise utilities for poor power quality that leads to costly equipment downtime.
3. **Integrate efficiency with industrial policy:** Link agro-processing park development, export-promotion programmes, and green-industrialisation plans with mandatory efficiency standards.

Summary: Energy cost is not just an operational issue—it is a **strategic determinant of competitiveness**. Addressing it through **targeted financing, hybridisation, and regulatory reform** will unlock productivity gains, create rural jobs, and improve food security. These findings provide the evidence base for Chapter 4's recommendations on **financing mechanisms, incentive design, and policy frameworks.**

Table 8: Financing roadmap for energy efficiency in African food processing

Financing instrument	Target processor segment	Priority technologies and interventions	Expected ROI and payback	Strategic rationale
Results-based financing (RBF)	Small and medium processors in >20% OPEX band	Solar–diesel hybrids, battery storage, high-efficiency pumps	3–5 years	De-risks CAPEX, accelerates renewable adoption, reduces diesel consumption by 20–40%.
Concessional credit lines (through DFIs and local banks)	Small and medium processors (USD 50k–5M revenue)	Efficient boilers, chillers, steam line insulation, IE3 motors	2–4 years	Unlocks high-ROI retrofits with limited upfront liquidity and improves competitiveness.
Energy service company (ESCO) and pay-as-you-save models	Micro and small processors (<USD 500k revenue)	Lighting upgrades, motor replacements, VSD retrofits	<3 years	Addresses CAPEX barrier for the smallest enterprises and enables repayment from verified savings.
Green bonds and carbon finance	Large processors (>USD 5M revenue)	Waste heat recovery, biomass boilers, large-scale PV	4–7 years	Monetises GHG reductions, aligns with ESG commitments, and attracts institutional capital.
Grant-funded energy audits	All processors, prioritising SMEs	SEC benchmarking, metering installation	Immediate (soft measure)	Generates data needed for credit appraisal and performance-based financing.
Tariff incentive schemes (off-peak pricing, time-of-use tariffs)	All grid-connected processors	Load shifting, demand management	1–2 years	Improves grid utilisation, reduces peak diesel generator set use, and stabilises processor costs.

Key takeaways for donors and policymakers

- **Highest impact:** Direct resources toward SMEs in the **31–40% and >50% OPEX bands**, where energy cost relief has the largest survival effect.
- **De-risking matters:** Use blended finance to crowd in private capital. Guarantee schemes can accelerate local bank lending for efficiency upgrades.
- **Data-driven approach:** Mandate SEC tracking and reporting as a precondition for concessional finance—building a robust dataset for future carbon market participation.

Key metric and benchmarks

To compare energy performance across diverse food processing operations, the study adopts **megajoules per kilogram (MJ/kg)** as the standard measure of energy intensity. While many processors typically record electricity in kilowatt-hours (kWh), diesel in litres, and biomass in kilograms or bags, converting all values to MJ/kg ensures consistency across different fuel types, equipment configurations, and production scales. For reference, 1 kWh is equivalent to 3.6 MJ, diesel fuel averages 38.6 MJ per litre, and dry firewood or charcoal yields roughly 15–18 MJ per kilogram.

A review of over 60 industry studies[13] revealed that the majority of reported SEC data—about 90%—was originally expressed in kWh per tonne or kWh/kg, with only around 10% presented in MJ units. The remainder used volumetric or mass measures such as litres or kilograms of biomass. For this analysis, all data was converted to MJ/kg and, where possible, disaggregated by processing stage (e.g., milling, drying, refrigeration, packaging) and energy type (electric versus thermal).

3.8 Energy sources

Energy use patterns in African food processing are shaped by a combination of key drivers: **grid access and reliability, fuel price volatility, processing technology choices, and seasonal production variability**. Across the nine value chains examined in this study, both the literature and the 2025 survey of 48 food processors confirm that African processors depend on a diverse energy mix that comprises grid electricity, diesel (both for backup and primary generation), biomass fuels (firewood, crop residues, charcoal), LPG, and—more recently—solar PV systems.

The wide variation in energy source shares across value chains reflects differences in **processing needs** (power-intensive vs. heat-intensive operations), **technology level** (modern roller mills vs. village hammer mills, efficient boilers vs. open-fire dryers), and **operational realities** (grid reliability, local fuel logistics, and seasonality). In general, power-dominated value chains such as cereals, nuts, and dairy lean heavily on electricity, while heat-dominated chains such as fruits, vegetables, and spices use higher shares of biomass or LPG.

3.8.1 Grid electricity

Grid electricity remains the primary energy source for most mechanised processors. In cereals, electricity dependence ranges from 30% in rural mills that rely on generator sets to 100% in large industrial roller mills connected to more reliable grids. Nuts and seeds processors are the most electricity-reliant of all, sourcing 90–100% of their energy from the grid or captive power plants, with diesel use almost negligible. In dairy processing, electricity serves a dual role. It maintains refrigeration and operates processing lines, with reported shares ranging from 40–56% of total energy use.

Reliability challenges remain pervasive. Frequent outages, voltage dips, and scheduled load-shedding disrupt production schedules, forcing many processors to invest in standby generators. Where grid quality is high, electricity dominates; where it is poor, diesel dependence rises sharply.

3.8.2 Diesel

Diesel plays a dual role in African food processing—both as a backup power source and as direct thermal energy for heat-intensive processes. Its prevalence is highest in sectors or locations with severe grid instability or a complete absence of grid access.

[13] This includes energy audit reports and post audit reports sourced from grey literature and SNV Uganda IMEU project in Uganda where 17 audit reports of food processors were reviewed and analysed.

Survey results show diesel contributions ranging from **2% to 100%**, with extreme cases reported in vegetable processing[14] and certain off-grid starchy root facilities. Mixed cereal–fruit processors reported diesel shares as high as **85%** where thermal demand is high and grid reliability is low.

The financial impact of diesel dependence is significant. In Nigeria, for instance, the 2023 removal of fuel subsidies tripled generator operating costs—undermining competitiveness and driving increased interest in solar–diesel hybrid systems to reduce daytime generator use.

3.8.3 Biomass and firewood

Biomass fuels—including firewood, charcoal, and crop residues—remain widely used, particularly in heat-intensive operations and small-scale processing where capital for modern boilers or dryers is lacking.

In fruit processing, firewood can contribute up to **60% of total thermal input**, particularly for drying and concentrate preparation. Dairy processors in the surveyed group report firewood shares of **18–48%**, mostly for pasteurisation. Rural honey and spice processors rely on biomass dryers, though hybrid solar-biomass systems are beginning to spread.

While biomass is often inexpensive or internally sourced, its inefficient combustion results in high specific energy use and deforestation concerns, making it a priority area for clean energy interventions.

3.8.4 LPG and furnace oil

LPG is used for processes that require controlled heat such as spice roasting, dairy pasteurisation, and vegetable blanching—with typical shares of 10–15% where adopted. Furnace oil use is rare but still observed in some cereal drying and starch processing facilities.[10]

Adoption is highest in export-oriented plants that need strict quality control (HACCP compliance) and in urban areas with good LPG logistics. High LPG price volatility, however, limits uptake for many smaller processors.

3.8.5 Solar PV and other renewables

Solar PV adoption in African food processing remains modest but is growing steadily, particularly in higher-value and modular operations. Evidence from the 2025 survey of 48 processors shows that honey and spice processors have the highest level of integration, with some reporting 40–95% of electricity demand supplied by solar PV in hybrid systems.[1] Fruit and vegetable processors have smaller but growing shares (5–8%), often in the form of solar-powered cold rooms

The rise of commercial and industrial (C&I) solar in Africa

Why it matters: The growth of the **C&I solar market** is reshaping how African food processors manage energy. It offers a scalable pathway to **cut diesel costs, stabilise power supply**, and **meet sustainability targets** in line with national energy transition plans.[4]

Market growth:

- Installed C&I solar capacity in countries in East and West Africa, surpassing 500 MWp by 2024, with annual growth rates of 30–35% since 2021 (IRENA 2023).
- Top adopters include Kenya, Nigeria, Ghana, and Uganda, where rising grid tariffs and load-shedding events make PV economics highly attractive (BNEF C&I Solar Outlook 2024).

Business models:

- **Power purchase agreements (PPAs):** Third-party ownership models allow processors to pay only for energy consumed, avoiding CAPEX.
- **Leasing and rent-to-own:** Favoured by mid-sized processors with seasonal cashflow constraints.
- **Hybrid PV–diesel–battery systems:** Designed to cut generator set runtime by **30–60%** and improve voltage stability (CLASP Case Studies 2024).

Key drivers:

- **Falling PV prices** (≈80% reduction since 2010).
- **Policy support** in select markets (net-metering, wheeling frameworks).
- **Corporate sustainability targets** set by buyers and export markets.

Remaining barriers:

- **Limited access to affordable debt financing,** especially for small processors.
- **Unclear grid-interconnection rules** and lack of standardised PPA frameworks in some markets.

Relevance for food processing:
Surveyed processors with solar hybrid systems reported:

- **Fuel cost savings** up to **40%**.
- **Improved production uptime** during load-shedding events.
- **Reduced generator maintenance costs**, lowering OPEX over the long term.

[14] Tomato Jos Farming & Processing Limited, located in rural Nigeria (Kaduna State), reported depending entirely on diesel for operations.

and drying units in smaller facilities. Cereal and dairy processors are piloting rooftop solar systems to offset daytime milling and refrigeration loads, reducing their dependence on diesel generators during peak hours

In Uganda, the snack processor energy audit conducted during this study revealed a 250 kWp solar system contributing 24% of annual energy needs. Likewise, an egg processing facility with a 54 kWp rooftop system was meeting nearly 50% of its total electricity demand from solar PV—showcasing solar's potential to reduce base-load demand and improve power reliability.

While the benefits are clear, barriers to wider adoption remain:

- High upfront capital expenditure (CAPEX) for solar systems.
- Limited access to concessional financing or long-term PPAs, especially for SMEs.
- Regulatory uncertainty in some markets regarding grid interconnection and net-metering rules.

However, successful deployments—as in Kenya, Uganda, and Nigeria—demonstrate strong operational and cost benefits.

3.8.6 Energy use patterns across food value chains

The combined evidence from survey data and literature shows distinct energy mix patterns. Electricity remains the backbone of processing energy supply. However, its share varies widely depending on process intensity, technology level, and grid reliability. Diesel is heavily used where grids are unreliable or absent. Firewood and other biomass sources dominate thermal energy supply in rural and small-scale settings, while LPG is chosen for quality-critical applications. Solar PV, though still a minor contributor, is growing rapidly where cost and reliability pressures justify investment.

Ranges represent the lowest to highest contribution of each energy source observed among surveyed facilities, triangulated with literature benchmarks. The wide ranges reflect variations in processing technology, scale, grid quality, and location. These energy constraints have direct nutritional implications: unreliable heat and cold supply disproportionately affects processing of nutrient-dense foods—such as dairy, fruits, vegetables, and fortified staples.

3.9 Energy use across processing stages

In African contexts, the distribution of energy across food processing stages reflects differences in product characteristics, technology adoption, and supply chain maturity.

The four main processing stages—primary processing, thermal processing, cooling and cold storage, and packaging—each contribute differently to overall SEC, measured here in MJ/kg.

Thermal processing is generally the most energy intensive, particularly for heat driven operations like drying, pasteurisation, and baking. Cooling is critical for perishable commodities, while primary processing dominates in mechanical transformation chains such as cereals and legumes. Packaging, though typically a smaller contributor, still accounts for a meaningful share of energy use in automated plants.

Survey results, audit data, and literature review all confirm that thermal processing dominates total energy demand in most African food industries, often consuming more than half of total SEC. This is particularly evident in dairy pasteurisation, grain drying, fruit concentration, and vegetable canning, where high temperatures and prolonged heating times are required. Cooling plays a disproportionately large role in dairy, meat, and high value fruit supply chains, often determining product shelf life and export viability. Primary processing remains the core electrical load in grain and legume milling, while packaging emerges as a growing share in modern, export-oriented facilities.

Table 9: Summary of energy source share and contribution by food value chain (survey and literature)

Value chain	Grid electricity (%)	Diesel (%)	Firewood (%)	LPG (%)	Solar PV (%)
Cereals and cereal products	30–100	2–100	0–5	–	–
Starchy roots and tubers	0-100	0–100	–	–	–
Beans and legumes	40–50	5–15	10–20	–	–
Dairy	40–56	4–25	18–48	0	1
Fruits	30–65	0–5	0–60	70	20
Vegetables	0–100	100	30–40	10–15	5–8
Nuts and seeds	90–100	1	4	–	–
Honey and spices	30	30	0	0–5	40–95
Animal meat and eggs	60	10	–	–	30

3.9.1 Primary processing

Primary processing refers to the initial mechanical or chemical transformation of raw materials into intermediate food products—such as milling cereals into flour, dehulling legumes, pressing oilseeds, or butchering meat. Across the survey and audits, these operations are **predominantly electricity driven**, relying on motors, conveyors, and grinders. SEC at this stage varies considerably with technology: small hammer mills and manually fed grinders typically consume **0.27–0.42 MJ/kg**, while large roller mills with integrated cleaning and conditioning systems record **0.4–0.8 MJ/kg**. Facilities with modern, variable speed drives and optimised milling sequences achieve the lowest SEC. Older belt driven motors, however, result in energy penalties of 10–20%.

3.9.2 Thermal processing

Thermal processing encompasses all heat based transformation and preservation methods, from pasteurisation and sterilisation to drying, baking, and frying. In African food industries, this stage is often the **largest single energy consumer**. For example, grain drying can require **1.0–1.5 MJ/kg**, while fruit juice concentration and milk spray drying can exceed **2.0 MJ/kg**.

Fuel choice varies by facility size and location: small processors rely on biomass fuels such as firewood or crop residues; mid-sized and large plants use diesel, furnace oil, or LPG for greater control; and a growing minority employ electric heating where grid power is reliable. Efficiency gaps are common—uninsulated steam lines, poor heat recovery, and oversizing of boilers all contribute to wasted fuel.

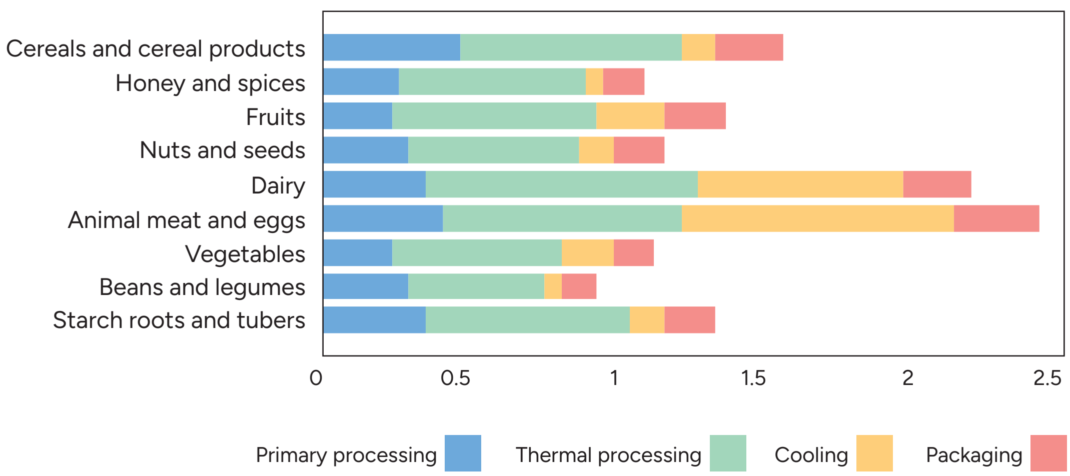
3.9.3 Cooling and cold chain

Cooling is critical for perishables. Dairy plants, meat processors, and fruit exporters all depend on reliable refrigeration to preserve product quality. In dairy, chilling raw milk to 4°C within hours of milking is non negotiable: energy audits show chilling a tonne of milk can consume **180–360 MJ**, depending on equipment efficiency and insulation quality. Cold storage of dairy products, meat, or fresh fruit can add another **0.1–0.2 MJ/kg/day** over the storage period. Weak cold-chain performance is a major nutrition barrier across the region, driving spoilage of high-value, high-nutrient foods—especially animal-source products and fresh produce—despite high burdens of protein and micronutrient deficiencies.

Table 10: Typical energy use by processing stage (MJ/kg)

Value chain	Primary processing	Thermal processing	Cooling	Packaging
Starchy roots and tubers	0.30	0.60	0.10	0.15
Beans and legumes	0.25	0.40	0.05	0.10
Vegetables	0.20	0.50	0.15	0.12
Animal meat and eggs	0.35	0.70	0.80	0.25
Dairy	0.30	0.80	0.60	0.20
Nuts and seeds	0.25	0.50	0.10	0.15
Fruits	0.20	0.60	0.20	0.18
Honey and spices	0.22	0.55	0.05	0.12
Cereals and cereal products	0.40	0.65	0.10	0.20

Figure 3: Energy consumption by processing stage (MJ/kg)



Audit evidence shows that **inefficient chillers, poor insulation, and a lack of heat recovery** are widespread. Modernisation—such as adopting high coefficient-of-performance (COP) chillers, regenerative heat exchangers, and solar-powered ice banks—is emerging in Kenya and Uganda, but scale remains limited.

3.9.4 Packaging

While packaging consumes less energy than processing or cooling, it is not insignificant—especially in automated plants producing export-ready goods. In a Nigerian breakfast cereal plant, packaging accounted for about **9 MJ/tonne**, or 18% of processing energy, mostly from electricity used to run automated filling and sealing machines.

Meat and dairy plants with vacuum seal packaging or form-fill-seal machines see similar proportional contributions. Energy efficiency opportunities include installing high-efficiency motors, optimising compressed air systems, and adopting automated standby modes on conveyors.

4 Energy intensity of food processing in Africa

This section examines the specific energy consumption (SEC) across nine major African food value chains and compares them with global benchmarks. It identifies the primary energy-consuming processes, the most inefficient segments, and the types of energy used, drawing from survey data, on-site audits, and recent literature. It also highlights operational patterns and inefficiencies that could be addressed through improved energy management.

Overall, the analysis confirms that African processors operate at higher SECs than modern global facilities in most value chains—often due to older equipment, lack of automation, poor maintenance, and heavy reliance on inefficient thermal systems. While efficient modern plants in Europe or Asia achieve SECs close to the lower bound of benchmarks, African averages are frequently **30–100% higher**, especially in **heat-intensive** or **refrigeration-dependent** operations.

4.1 Cereals and cereal products

Cereals—including maize, rice, sorghum, and wheat—are a cornerstone of African diets and a major focus for agro-processing. On-farm cultivation uses relatively little mechanised energy, but post-harvest stages—milling, drying, and baking—are highly energy-intensive.

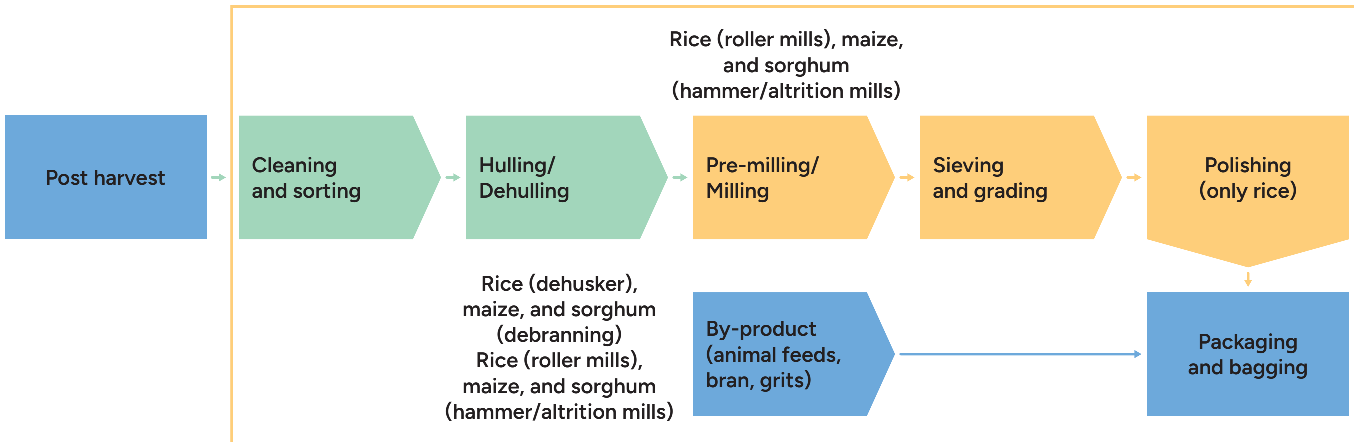
Milling: Modern roller mills globally achieve SECs of **0.18–0.30 MJ/kg**. In Africa, large roller mills with good maintenance can approach **0.27–0.40 MJ/kg**, which is close to global practice. However, many smaller or older mills exceed **0.5 MJ/kg**, and village-level hammer or plate mills often operate at **1–2 MJ/kg**, with inefficient units exceeding **5 MJ/kg**[2]. This variation reflects differences in motor efficiency, throughput, and the degree of reliance on diesel power. Mandatory fortification policies—such as adding vitamins and minerals to flour —can be most effectively implemented when paired with energy-efficient milling and processing systems that minimise heat losses and preserve nutrient stability.

Drying: Grain drying is another major energy sink. Efficient flat-bed or silo dryers consume around 1.0–1.5 MJ/kg of product equivalent, but African commercial dryers typically operate at **1.5–3.0 MJ/kg** because of low thermal efficiency (30–50%) and lack of insulation.[3] In rural contexts, sun-drying is still widely practised. While it avoids fuel purchases, it lengthens processing time and risks product quality.

4.1.1 Grain (maize, rice, sorghum)

Energy intensity in maize, rice, and sorghum milling varies sharply by **scale and technology**. Large-scale industrial roller mills in Africa operate at **0.23–0.36 MJ/kg**, while medium-scale electric mills average **0.3–0.8 MJ/kg** depending on mill configuration and motor efficiency.

Figure 4: Stages of cereal processing



Case example: Five maize mills in Uganda

Energy audits of five maize processors in Uganda reveal wide SEC variation:

Facility	Electricity SEC (MJ/kg)	Diesel/thermal SEC (MJ/kg)	Total SEC (MJ/kg)
Grainpulse Ltd	0.50	0.58	1.08
Arise and Shine	0.396	—	0.396
Karemera Industries	0.27	—	0.27
Asante Agro	0.42	—	0.42
Akalo Cooperative	0.764	0.764	0.764

Source: Author analysis, 2025 for SNV IMEU Reports.

Energy audits of five processors showed SECs ranging from **0.27 MJ/kg** in a medium electric mill to **1.08 MJ/kg** in an integrated large mill with in-house drying. Diesel-reliant facilities consistently reported higher SECs than grid-connected ones.

Small diesel mills typically consume **0.6–2.0 MJ/kg**, and village-level hammer mills may exceed **5 MJ/kg**[2]. Wet-milling processes can reduce the milling load to **≤1 MJ/kg**, but this is offset by post-drying requirements.

Upgrading to high-efficiency motors, improving roller and screen settings, and regular maintenance can close much of the gap. For example, a well-maintained hammer mill can operate at **0.25 MJ/kg**, while poorly maintained equipment can double that figure. Overall, modern cereal mills can achieve **0.10–0.30 MJ/kg** of finished product, while legacy installations often consume **0.5 MJ/kg** or more.

Figure 4 illustrates the energy-consuming stages of cereal processing. Assigning SEC values to each block—for example, **0.2–0.5 MJ/kg** for cleaning/milling, **1–2 GJ/t** for drying, and **0.1–0.3 MJ/kg** for polishing—enables modelling of total plant energy demand across maize, rice, and sorghum lines.

4.1.2 Breakfast cereal

Producing breakfast cereals and instant grain products involves multiple **energy-intensive steps**, including cooking, extrusion, drying, and toasting. Global benchmarks place production SECs at **4–8 MJ/kg**[2], while plants in African countries typically operate at **5–12 MJ/kg**[2]. The higher range in Africa reflects **older ovens** and dryers, lack of insulation, absence of heat recovery, and unstable power supplies that reduce utilisation.

Improving insulation, installing exhaust heat recovery systems, and adopting a more reliable or hybrid power supply can yield substantial savings. Many bakeries and cereal plants across Africa continue to rely on diesel-fired ovens or small batch operations, magnifying both SEC and production costs.

Key processes and inefficiencies: Drying (both grain moisture reduction and cereal toasting) and extrusion dominate energy demand. Across Africa, much grain drying is still conducted through sun-drying, which minimises fuel use but delays processing and risks quality loss. Milling with older diesel engines is also far less efficient than with grid-connected electric motors. Shifting to modern renewable-powered mills, combined with oven and dryer efficiency upgrades, offers the most immediate opportunities to reduce SEC across the cereal value chain.

4.2 Nuts and seeds

Nut and oilseed processing combines **mechanical operations** (shelling, pressing, grinding) with **thermal steps** (roasting, conditioning, drying). These stages make the chain moderately to highly energy-intensive, depending on the scale of operation and technology used.

Groundnuts and oilseeds: Global best-practice SECs for oilseed drying and pressing are **3.6–6.5 MJ/kg**[4]. African facilities report higher averages of **5.4–9.0 MJ/kg**, particularly where diesel-fired boilers or biomass stoves dominate.[4] Inefficient thermal management, poor insulation, and batch-based operations all contribute to the higher range. Plants with reliable grid power and efficient electric presses can achieve SECs much closer to global norms.

Cashew nuts: Cashew processing is among the most energy-intensive nut subsectors. African cashew plants record SECs of **10–14 MJ/kg**, compared with global benchmarks of **~8–10 MJ/kg**[4]. The excess reflects **manual shelling, small-batch roasting over open fires or diesel burners**, and low levels of process integration. Improved thermal insulation, adoption of LPG or biogas systems, and larger-scale mechanised shelling lines have been shown to cut SEC significantly in pilot projects.

Case example: Macadamia nuts in Kenya

One macadamia processor operating on grid electricity with modern shell-cracking machines and hot-air dryers reported SECs of **~0.33 MJ/kg** for mechanical shelling and drying steps, close to global best practice. In contrast, small rural processors using open biomass fires for roasting consumed nearly double that amount, underscoring the **scale and technology efficiency gradient.**

Variation drivers: The survey and audit evidence reveal three main causes of inefficiency in nuts and seeds processing:

- **Scale effects:** Small rural processors report SECs two to three times higher per kg than medium and large plants.
- **Fuel mix:** Diesel-fired or biomass systems, especially without controlled combustion, raise SECs compared to efficient electric pressing lines.
- **Technology age:** Absence of insulation, poor air–fuel controls, and older roasting equipment lead to high thermal losses.

Overall, African nuts and seeds processing can be competitive with global benchmarks where grid-reliable mechanised lines are in place. However, the majority of processors—particularly cashew and groundnut plants operating at small scale—remain **significantly less efficient**, reinforcing the need for targeted support to improve thermal efficiency and promote fuel switching.

4.3 Starchy roots and tubers

Starchy roots and tubers[15] —including cassava, yam, and potato—are central to African food systems and processed into *gari*, flours, chips, and starches. Energy intensity varies widely depending on the product: while some traditional products rely on **low-commercial-energy techniques** (sun-drying, biomass roasting), industrial snack products are highly energy-intensive.

4.3.1 Cassava (*gari*)

Cassava processing combines **mechanical stages**—peeling, grating, pressing—with **thermal stages**—roasting and drying. These latter steps dominate energy use. Global benchmarks place SECs for *gari* production at **0.43–0.9 MJ/kg[5]**, while African processors that fully account for biomass use report SECs in the range of **0.65–1.05 MJ/kg[5]**.

Our own survey dataset, however, produced **implausibly low values**, in some cases as little as **0.00007–0.26 MJ/kg**. This discrepancy arises because most facilities did not record **firewood or charcoal consumption**, even though roasting pans and drying stages in cassava processing rely heavily on biomass fuels. These omissions mean that **reported SECs underestimate true energy use by one to two orders of magnitude.**

The **roasting stage** is the most energy-intensive component. Small-scale processors still rely on **open wood-fired pans**, which are highly inefficient and labour-intensive. By contrast, industrial *gari* plants that use **improved insulated roasters** or **hybrid biomass/LPG systems** can approach global efficiency levels. Solar-assisted dryers piloted in West Africa have also demonstrated the potential to cut fuel use while stabilising output quality.

A recent study of cassava flour and chip processors reported total energy consumption of approximately **2.2 MJ/kg** of root when both mechanical and thermal loads were included (Rasul et al. 2024). Although drying dominated the load, motor-driven grating and pressing also accounted for a significant share. Upgrading to **high-efficiency motors**, improving **power reliability**, and introducing **efficient thermal device**s can therefore reduce SEC across the chain.

In many West African operations, *gari* production still combines **sun-drying** and **wood-fired roasting**. While sun-drying avoids purchased fuel, it delays processing and increases the risk of spoilage. Mechanised roasters and industrial ovens raise absolute energy demand but provide better throughput and quality. Transitional options—such as **improved cookstoves, insulated roasting drums, and solar-assisted dryers**—offer a middle path, lowering overall SEC while reducing dependence on traditional biomass.

4.3.2 Snack products (chips/fries)

Potato crisps and french fries rank among the most energy-intensive processed foods. Global SECs are **12–15 MJ/kg[6]**, while African processors often operate at **15–20 MJ/kg[6]**. Much of this excess stems from **older fryers without heat recovery**, poor oil management, and reliance on inefficient thermal systems. Artisanal frying, often conducted over biomass fires, is even less efficient due to uncontrolled combustion and extended processing times.

Modern frying systems with **integrated heat recovery, improved oil filtration, and better insulation** can cut energy consumption significantly, but adoption remains limited in African contexts.

[15] Also includes: Flours and starches (e.g., potato starch), snacks and crisps, fermented products (e.g., *gari*).

4.3.3 Bakery and other processed foods

Bakeries must heat ovens for bread and pastries; breweries boil mash and sterilise; confectioneries cook syrups; snack factories fry chips or extrude and bake products. These operations consume substantial energy, mostly in the form of heat. The global average energy for bakery products is about 5.21 MJ/kg (World Bank, 2025; Ampah et al., 2021), which encompasses both the oven or furnace energy and other utilities. Traditional brick ovens or drum roasters in Africa (e.g., for peanuts) can be fuel-inefficient, losing much of their heat to their surroundings.

Modern ovens with insulation, continuous lines, and heat recovery (using exhaust heat to preheat incoming air) can drastically improve efficiency. Emerging technologies offer further potential: for instance, infrared baking, microwave baking, or ohmic heating can sometimes reduce process time and energy use. Novel food processing technologies like pulsed electric field (PEF) treatment, high-pressure processing, or ultrasound-assisted drying are being researched for their ability to achieve preservation with lower energy and better quality (FAO, 2025).

That said, for much of Africa's food industry in the near term, the focus is on improving conventional thermal processes: e.g., switching from inefficient wood-fired batch roasters to efficient LPG or biogas burners, adopting solar cookers/ovens for community bakeries, using pre-heating and heat recovery in continuous processes, and training operators on optimal furnace control. These measures can yield fuel savings of 20–50% in many cases (FAO, 2025).

4.4 Beans, legumes and pulses

Legumes such as beans, lentils, peas, and soybeans generally have moderate SECs in basic processing but can become energy intensive when cooked, canned, or converted into dairy alternatives. Primary processing—cleaning, splitting, milling—has SECs similar to cereal milling (0.10–0.30 MJ/kg in efficient setups). Many African processors operate at higher figures due to outdated hammer mills or diesel dependence.

Cooking and canning add several MJ/kg to the total. Industrial canning involves soaking, cooking, and sterilisation. In Africa, full canning lines are rare, with most legumes sold for household cooking—shifting the large thermal load to end users, where inefficient biomass cookstoves drive very high energy use.

Dairy alternatives such as soy milk and yoghurt require grinding, cooking, and sometimes UHT treatment. Global SECs are 2–5 MJ/kg milk equivalent, but small African processors often operate at the upper end due to small batch heating and manual handling.

Efficiency gains are possible via:

- Pressure cookers and modern retorts with steam recirculation.
- Pre processing (parboiling, pre-soaking) to shorten cooking times.
- Solar cookers or hybrid systems for community kitchens.

4.5 Dairy

Dairy processing is one of the most energy-intensive value chains, dominated by thermal loads for pasteurisation, cooking, and evaporation, and electrical loads for refrigeration and pumping.

Dairy thermal process: Pasteurisation—heating milk to approximately 72°C then cooling it—is typically equipped with regenerative heat exchangers that recover over 90% of process heat. Even so, net thermal energy for pasteurising liquid milk runs around 100–200 MJ per tonne of milk, plus 0.1–0.2 MJ per tonne of electricity to power pumps, mixers and refrigeration compressors.

When milk is spray dried into powder, however, thermal demand soars: global benchmarks place milk powder production at 10 MJ per kilogram of powder, equivalent to roughly 1.3 MJ per kilogram of raw milk (given an 8:1 milk-to-powder ratio). African case studies confirm a fourfold increase in specific energy use during powder seasons, with total energy (heat and electricity) around 2.5 MJ per kilogram of milk processed into powder. Other thermal-intensive dairy processes include cheese cooking—averaging 14 MJ per kilogram of cheese—and hot-water sanitation of equipment.

Efficiency levers:

- Maximising regenerative-heat recovery (e.g., cascade preheating of incoming milk and wash water).
- Upgrading boiler technology (high-efficiency gas or biomass steam generators).
- Implementing solar thermal or biogas systems for low-grade heat.

4.5.1 Liquid milk

Processing liquid milk involves pasteurisation, homogenisation and rapid cooling. Global energy benchmarks for fluid milk processing and packaging lie at **0.5–0.6 MJ per litre**; in many African plants—where older equipment and self-generated electricity prevail—values range from **0.6 to 0.8 MJ per litre**. Electrical demand is driven by homogeniser pumps and plate coolers, while refrigeration consumes up to 20% of total energy.

- **Global benchmark:** 0.5–0.6 MJ per L for pasteurisation, homogenisation and cooling.
- **African case:** A Nigerian plant averaged 0.66–0.70 MJ/L over 2011–2015 (Alabi and Diji 2021), ~15% above the global norm due to older boilers and backup diesel generators.
- **Efficiency gap:** Upgrading to high-efficiency plate exchangers and eliminating generator dependence could trim SEC to match global best practice.

4.5.2 Milk powder

Spray drying to produce milk powder is the single most energy-intensive dairy operation. Evaporating nearly 90% of water content requires sustained high-temperature steam and hot-air circulation. Modern spray dryers achieve around **10 MJ per kilogram** of powder, but outdated units in Africa may exceed **12 MJ/kg**. No refrigeration is needed post-drying, but packaging and storage of hygroscopic powder demand tight moisture control.

- **Milk powder:** supports 'last-mile nutrition access' despite high SEC.
- **Global benchmark:** 10 MJ/kg of powder (≈1.3 MJ per kg of raw milk, accounting for ~8:1 milk-to-powder ratio).
- **African example:** A Kenyan plant's powder season SEC rose from 0.6 MJ/kg (liquid phase) to 2.5 MJ/kg milk equivalent—nearly 4 times higher—due to older spray dryers and low-grade heat sources.
- **Opportunity:** Modern spray dryers and cascaded-evaporation systems with multi-effect evaporators can approach the 10 MJ/kg target, halving the current African SEC.

4.5.3 Yoghurt and fermented milk

Yoghurt production adds fermentation incubation—holding milk at 40–45°C for several hours—followed by cooling to 4°C. Total energy use typically reaches **2–3 MJ per kilogram** of yoghurt, combining heating (pasteurisation and incubation) and refrigeration. Equipment inefficiencies—such as imprecise temperature control and lack of insulated fermenters—can inflate this figure in smaller African plants. Yoghurt fermentation boosts probiotic content, making it a valuable vehicle for vitamin D and B-complex fortification when temperature-controlled incubation preserves nutrient stability.

- **Global figure:** ~2.2 MJ/kg including pasteurisation, incubation and cooling.
- **African indicator:** Smaller plants report 2.5–3 MJ/kg, reflecting heat losses from uninsulated fermenters and intermittent refrigeration.
- **Comparative insight:** Yoghurt SEC runs ~3–4× that of fluid milk due to the added fermentation holding step. Investing in insulated, automated incubation tanks can curb this overhead.

4.5.4 Cheese

Cheesemaking concentrates milk solids by coagulating and pressing curd, demanding both heat (for curd cooking at 35–55 °C) and cold storage during maturation. Plant-level energy use averages **8 MJ per kilogram** of cheese, but when including upstream farm feed and animal energy costs, total embedded energy can exceed **75 MJ/kg** for hard cheeses. Fresh cheeses (e.g., paneer, cottage cheese) require less ageing but still involve significant heating and brine chilling. Cheese concentrates protein, calcium and fat-soluble vitamins, so aligning cheesemaking with gentle heat profiles helps retain micronutrients while supporting potential fortification of processed or spreadable cheese types.

4.5.5 Butter and spreads

Butter production—churning cream and separating buttermilk—consumes moderate thermal energy for cream pasteurisation (≈1 MJ/kg) and refrigeration for storage. Total plant-level energy might be **3–5 MJ per kilogram** of butter. By contrast, margarine (oil-based) manufacturing bypasses animal feed inputs and high-grade heating, resulting in lower total energy footprints in the **tens of MJ per kilogram** range.

- **Global processing SEC:** 3–5 MJ/kg for cream pasteurisation, churning and cooling.
- **Contrast:** Margarine lines (oil-based spreads) consume only 1–2 MJ/kg in plant operations—~50 % of butter's processing energy—though total life-cycle SEC favours margarine even more strongly when feed inputs are included.

4.6 Fruits

Fruits in Africa span a spectrum from largely "fresh" supply chains—where energy use is confined to minimal handling—to modern processing lines for juice, jam, dried fruit and canning. Their high-water content means the two dominant energy sinks are **cold-chain refrigeration** (to preserve freshness) and **water removal** (drying, concentration). In the sections below, we integrate global averages, African benchmarks and our prior case studies (fruit juice, tomato paste, and pineapple) to compare SEC across fresh and processed fruit lines.

4.6.1 Fresh fruits

The main energy use for fresh fruits comes from **cold chain** requirements. If fruits are refrigerated from harvest to market, electricity is needed for cooling. In Africa, cold chain infrastructure is limited; only a fraction of produce is kept in cold storage. As a result, energy use is low, but post-harvest losses are high (up to ~37% of food lost between harvest and processing in African countries south of the Sahara). Where cold storage is used (e.g., export-oriented horticulture), energy might be significant. For example, cold storage of apples or bananas might add ~0.54–1.3 MJ/kg over the supply chain (Energy for Growth Hub, 2025). Fresh fruits deliver essential vitamins and antioxidants, and maintaining a functional cold chain is critical to slowing nutrient degradation—especially vitamin C—throughout storage and transport.

- **Global benchmark:** 0.54–1.3 MJ/kg (harvest to retail refrigeration).
- **African reality:** Limited refrigerated handling (<10%) yields **<0.1 MJ/kg** on average but incurs **25–37%** post-harvest losses.
- **Case study:** In export pack-houses for avocado and mango, refrigeration adds ~0.8 MJ/kg via older compressors and backup diesel generator sets.
- **Integration:** No direct SEC studies for fresh fruit beyond cold chain, but the **wasted embedded energy** in losses (sun-drying vs. cold storage trade-off) is a crucial inefficiency.

4.6.2 Processed fruits

Turning fruits into products (juice, jam, dried fruit, canned fruit) involves energy. A review of food manufacturing found that fruit and vegetable processing plants on average use around 4.2 MJ/kg (with ~1.1 MJ from electricity and 3.1 MJ from fuels like heat) (Ampah et al., 2021). This figure covers operations like washing, cutting, pasteurising (for juice), cooking (for jams), and dehydration. In Africa, juice pasteurisation plants or canneries may have similar energy profiles if operating with modern equipment. However, smaller-scale producers might use less-automated (but also potentially less-efficient) methods. Dried fruits produced traditionally (sun or solar drying) have negligible fuel use, whereas industrial dryers (e.g., for mango slices) consume several MJ per kg of water removed.

Global surveys of fruit-and-veg plants report an average of **4.2 MJ/kg** of product, split roughly **1.1 MJ/kg** from electricity and **3.1 MJ/kg** from thermal fuels. African small- and medium-scale operations exhibit wide variability around this benchmark:

- **Juice production:** Pasteurising and filling liquid juices consumes about **1–3 MJ/kg**; concentrating adds another **4–6 MJ/kg** of steam. Small plants in Nigeria report near **4 MJ/kg** in total, often due to boiler inefficiencies.
- **Jam and canning:** Boiling fruit–sugar mixtures and sterilising jars typically draw **4–8 MJ/kg**. Biomass-fired open pans can double heat use compared to steam-jacketed kettles.
- **Industrial drying:** Kiln dryers for mango, pineapple, or banana chips require **5–10 MJ/kg** of thermal energy to remove moisture, versus near-zero fossil input for sun and solar dryers.

Key processes and inefficiencies: Cold storage and dehydration represent two ends of the spectrum for fruits. Cooling inefficiencies (older refrigeration units, poor insulation, frequent power outages requiring backup generators) can raise energy per kg in Africa's nascent cold chains. On the processing side, inefficient boilers or dryers can waste energy—for instance, using open-pan boiling for jam is far less efficient than using steam kettles. Improving the energy intensity of fruit chains in Africa may involve expanding cold storage smartly (e.g., using solar-powered cold rooms) to reduce losses without incurring overly-high energy costs and upgrading processing with efficient technologies (e.g., heat recovery in juice plants).

Table 11: Global and African SEC by product type

Product type	Global SEC (MJ/kg)	African SEC (approx.)	Key drivers
Juice (liquid)	1–3	1–4	Pasteurisation and pumping
Juice (concentrate)	5–8	6–10	Evaporation energy
Jam and canning	4–8	5–10	Open-pan boiling vs. steam kettles
Dried fruit	3–7	5–12	Dryer type (solar vs. kiln)

Source: Author compiled from 2025 survey data.

4.7 Vegetables

The vegetable value chain shares many characteristics with fruits but often involves different post-harvest handling (more immediate cooking or local sale, less sugar content). Vegetables in many African countries are largely consumed fresh or cooked at home, with minimal processing, but when processing does occur (e.g., frozen vegetables and canned tomatoes) energy use comes into play. A large portion of vegetables are sold in local markets without refrigeration, meaning energy input is mainly in transport (which might be a truck or even just bicycles in rural areas).

However, **urban cold chains** for vegetables (like supermarket supply of tomatoes, peppers, etc.) are emerging in Africa. Electricity for cold rooms and refrigerated trucks then contributes maybe 0.1–0.3 MJ/kg per day of refrigeration. If vegetables are imported or exported, the transport energy can dominate (as noted, air freight of fresh vegetables like green beans can be ~60 MJ/kg, including cooling, whereas ocean freight is much lower).

Processed vegetables: Common processes include canning, pickling, freezing, and drying.

- **Tomato paste:** At 0.34 MJ/kg, thermal energy for sterilisation (diesel boiler) dominates, making it far more efficient than typical vegetable canning lines.
- **Canning and preserves:** Global averages (~4–8 MJ/kg) rise to 5–10 MJ/kg in African facilities using open-pan biomass or diesel boilers.
- **Freezing:** Blast freezing plus storage typically consumes 0.3–0.5 MJ/kg of electricity; virtually absent in most African chains.
- **Drying:** Sun-drying remains prevalent, but industrial dryers for okra or leafy veg require 5–10 MJ/kg of heat.

Key processes and inefficiencies: Much like fruits, the inefficiencies in vegetable chains include a lack of refrigeration, leading to waste (an indirect inefficiency) and outdated processing methods where they exist. For example, traditional open-fire roasting of peppers or eggplants for certain products wastes heat. Also, where canneries exist, if they use old boilers or lack insulation, energy per kg is higher than necessary. Inefficient processing (longer heating times) may exacerbate nutrient degradation. On the other hand, an inefficiency in developed contexts—heated greenhouses—is not common in many African countries, meaning African vegetables avoid that energy cost. As the region develops, a key challenge will be adopting efficient greenhouse and irrigation technologies (e.g., solar-powered drip irrigation instead of diesel pumps) so that increased production does not come with disproportionate energy use. Solar or hybrid drying systems also help preserve vital micro nutrients.

4.8 Animal meat, poultry and eggs

Animal protein processing in Africa encompasses **primary slaughter** and a small—but growing—set of **value-added lines** such as poultry processing, sausages, and canned meats. Energy use in these chains is dominated by **thermal sanitation, scalding or defeathering, and cold-chain refrigeration**, while mechanical loads for cutting, conveying, or packaging play a smaller role. Integrating global benchmarks with African survey and audit data reveals that SECs in this value chain are generally within global ranges but tend toward the higher end due to **diesel backup generation, poor insulation, and scale inefficiencies.**

4.8.1 Primary meat processing

Primary meat processing (slaughter, evisceration, washing, chilling, and basic cutting) excludes upstream farm-gate energy and feed inputs.

- **Global benchmarks** place plant-level SECs for slaughter and chilling at **2–5 MJ/kg of carcass**[15].
- **African facilities** report SECs of **3–5 MJ/kg**, reflecting higher refrigeration loads due to **diesel-powered generator sets** and poor insulation in chiller rooms.

Unit operations. Abattoir electrical use is typically **0.18–0.54 MJ/kg of carcass** for cutting and conveyors, while thermal sanitation and rendering consume an additional **0.1–0.2 MJ/kg**. Refrigeration loads add **2–4 MJ/kg**, but in African plants this often rises to **3–5 MJ/kg** where generator sets are used.

Inefficiencies and levers:

- Replacement of old boilers with **high-efficiency or biogas-fired units.**
- Heat recovery from rendering condensate to pre-heat wash water.
- Retrofitting chiller rooms with **variable-speed compressors and improved insulation.**
- Deployment **of on-site solar PV** to displace diesel use in refrigeration.

4.8.2 Poultry processing

Poultry processing includes scalding, defeathering, evisceration, washing, chilling, and packaging.

- **SEC ranges.** Global benchmarks are **2–5 MJ/kg of carcass**[15], and African processors fall within the same range but often at the higher end.
- **Load distribution.** Scalding and defeathering account for about **40–45%** of total energy, mechanical evisceration and washing for **~30%**, and chilling and packaging the remainder.

African plants frequently operate above **3 MJ/kg**, especially where refrigeration relies on diesel. Larger plants with integrated scalding and insulated systems demonstrate **clear scale efficiencies**, consuming closer to the **2 MJ/kg** benchmark.

Efficiency levers:

- Recovering heat from scald tanks for pre-heating.
- Installing **insulated scalders and automated defeatherers.**
- Optimising freezer loading and introducing **variable-speed compressors** to cut idle refrigeration losses.
- Efficient processing supports high-protein diets at lower energy cost.

4.8.3 Processed meats (sausages and jerky)

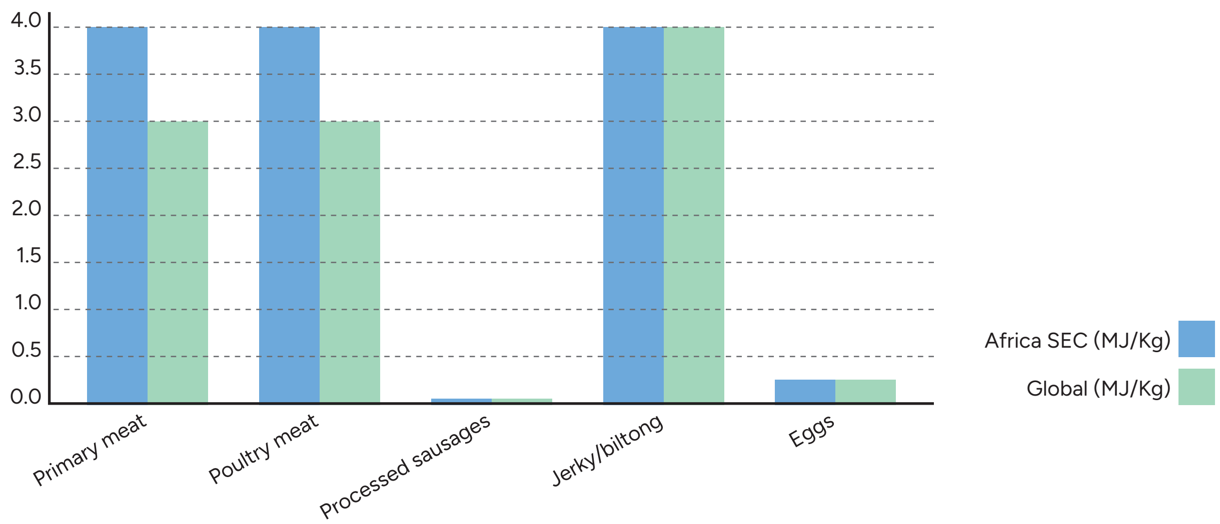
Energy intensity for processed meats varies widely by product:

- **Sausages:** Production is relatively efficient, with SECs as low as **~0.03 MJ/kg**, dominated by electrical mixing and short thermal cooking cycles.
- **Jerky and biltong:** Dehydration is much more intensive, typically requiring **3–5 MJ/kg**, whether electric dryers or biomass-fired systems are used.

Efficiency levers:

- Use of waste heat from boilers or biogas plants for drying.
- Installation of heat recovery systems on cooking kettles and dryers.

Figure 5: Animal meat, poultry, and eggs: SEC in African vs. global benchmarks



4.8.4 Eggs

Primary processing—washing, candling, grading, and packing—has minimal thermal demand. Electrical SEC is on the order of **0.05–0.1 MJ/kg** of eggs (including refrigeration in pack-houses).

Primary egg processing is among the least energy-intensive operations.

- **SEC ranges:** Both global and African benchmarks converge at **0.1–0.5 MJ/kg**[15], with most of the energy attributed to refrigeration in pack-houses.
- African plants relying on intermittent power often supplement with diesel generators, raising effective SECs toward the higher end of the range.

Overall, African meat and poultry processing SECs are **broadly aligned with global benchmarks**, but remain skewed toward the higher end of ranges due to:

- **Diesel dependence** for refrigeration and scalding in the absence of a reliable grid supply.
- **Thermal inefficiencies** from outdated boilers and uninsulated scalding systems.
- **Scale effects**, with smaller abattoirs and poultry processors reporting higher SECs per kilogram of output.

Efficiency improvements in boilers, scalding equipment, and refrigeration, combined with fuel substitution (biogas, solar-hybrid systems), represent the most promising levers to reduce SEC in this value chain. Low SEC in egg handling preserves their innate high nutrient density (protein, choline), provided cold-chain integrity is maintained.

4.9 Benchmarking African processors against global SEC standards

4.9.1 Overall observations of SEC in Africa

Across all value chains, benchmarking confirms that **African processors operate at higher SECs than global peers in most sub-sectors**, with a few exceptions. The gap is especially pronounced in **heat-intensive processes** (drying, frying, baking) and **cold-chain dependent operations** (dairy, meat, fruits, vegetables).

Cereals and cereal products:
African milling SECs for wheat and maize (0.10–0.36 MJ/kg and 0.12–0.30 MJ/kg) are close to global norms (0.18–0.30 MJ/kg). However, **multi-stage operations** (milling and baking or extrusion) rise to **4–11 MJ/kg** compared with **3.6–7.3 MJ/kg globally**. Breakfast cereals are particularly inefficient, consuming **5–12 MJ/kg in Africa** versus **4–8 MJ/kg globally**. These higher values reflect reliance on diesel-powered hammer mills, uninsulated ovens, and low utilisation rates.

Dairy:
Dairy processors in Africa consume **0.6–2.1 MJ/kg for liquid milk** (vs. 0.5–1.2 MJ/kg globally), **2.5–3.0 MJ/kg for yogurt** (vs. ~2.2 MJ/kg), **6–9 MJ/kg for cheese** (vs. 5–9 MJ/kg), and **6–10 MJ/kg for milk powder** (vs. 5–9 MJ/kg). The excess is largely due to **cold-chain dependence under unreliable grids**, forcing plants to rely heavily on diesel generator sets for refrigeration and spray drying.

Fruits and vegetables:
African juice processing averages **1–4 MJ/kg** (vs. 1–3 MJ/kg globally), concentrates **6–10 MJ/kg** (vs. 5–8 MJ/kg), and dried fruits **5–12 MJ/kg** (vs. 3–7 MJ/kg). Vegetables show similar gaps, with canning or blanching at **5–10 MJ/kg** in Africa (vs. 4–8 MJ/kg globally), and frozen vegetables **~0.6 MJ/kg** compared to **0.3–0.5 MJ/kg globally**. An extreme outlier was reported at **22 MJ/kg** for frozen vegetables, caused by very low production volumes against fixed energy loads—a clear example of the **scale efficiency trap**.

Nuts and seeds:
African oilseed pressing SECs (5.4–9.0 MJ/kg) exceed global ranges (3.6–6.5 MJ/kg), while cashew processing (10–14 MJ/kg) also exceeds global norms (~8–10 MJ/kg). These gaps are mainly due to **diesel boilers, open biomass roasting, and batch operations.**

Animal meat, poultry and eggs:
Primary meat processing in Africa consumes **3–5 MJ/kg**, compared to **2–5 MJ/kg globally**, while poultry meat is aligned at **2–5 MJ/kg**. Egg processing is efficient at **0.1–0.5 MJ/kg**, similar to global ranges. However, survey data often underreport diesel refrigeration, suggesting that true SECs are higher than reported.

Roots and tubers:
Survey data reported implausibly low SECs for cassava *gari* (0.00007–0.26 MJ/kg), but once biomass is included, corrected values are **0.65–1.05 MJ/kg**, aligning with global norms (0.43–0.9 MJ/kg). Potato products (chips and fries) are more energy intensive, with African plants at **15–20 MJ/kg**, exceeding global benchmarks of **12–15 MJ/kg**.

Honey and spices:
Honey extraction and spice processing SECs in Africa (**0.5–1.0 MJ/kg**) closely match global values. While absolute energy use is low, **small scale amplifies relative cost burdens** in these sectors.

4.9.2 Cross-cutting takeaways

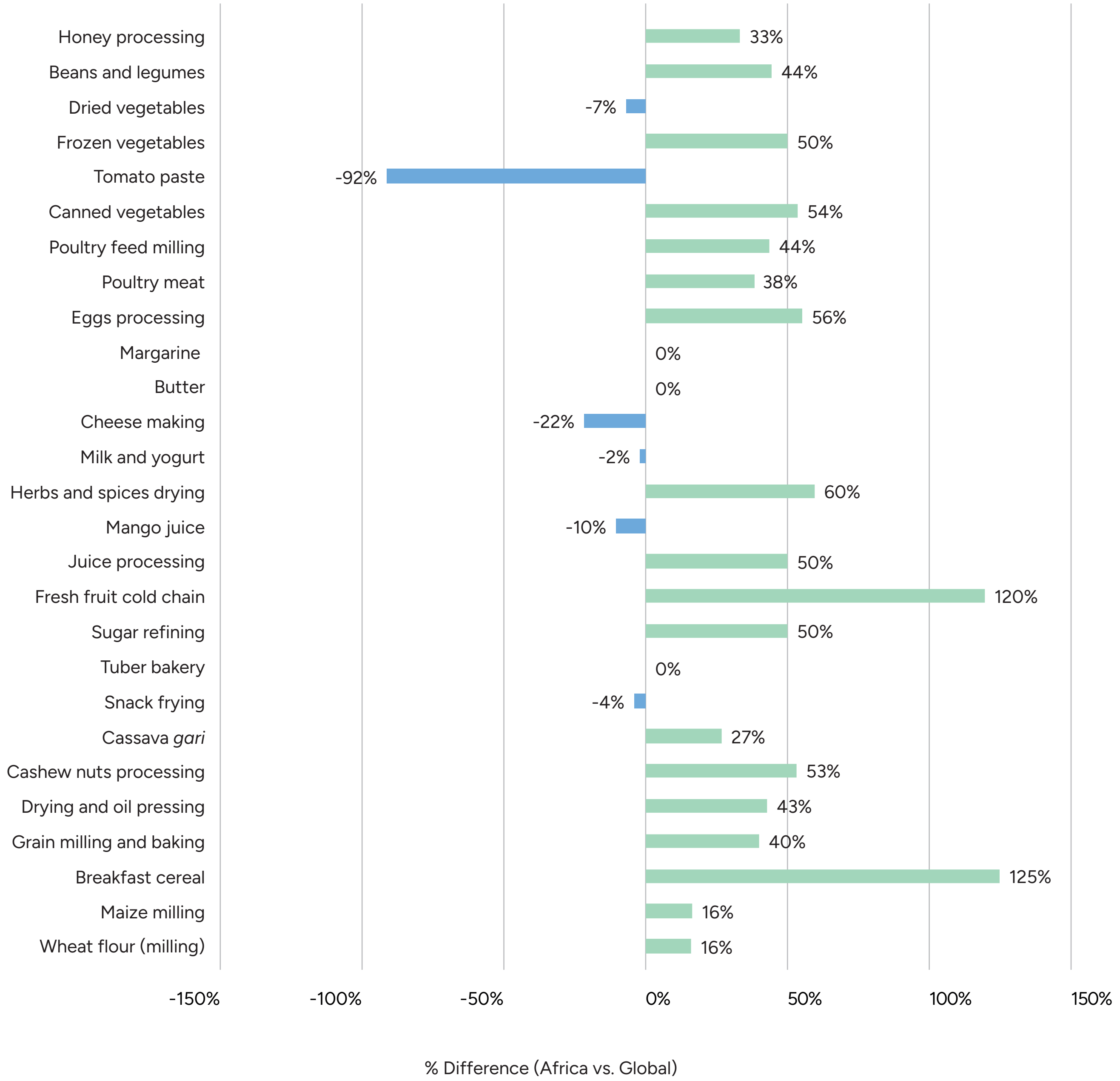
1. **Energy inefficiency is structural:** Dairy, cereals, fruits, and vegetables consistently exceed global benchmarks due to outdated boilers, uninsulated dryers, and poor refrigeration.
2. **Small processors face efficiency traps:** Low throughput magnifies fixed energy loads, especially in vegetables, fruits, and spices.
3. **Underreporting distorts survey data:** True SECs for roots, tubers, meat, and eggs are higher once traditional biomass and diesel backup are fully counted.
4. **Dual penalty for processors in African countries:** They pay more per unit of energy and use energy less efficiently per unit of product compared to global peers.
5. **Nutrition–energy linkages:** Energy inefficiencies across the supply chain contribute directly to nutrient losses—for example, cold-chain interruptions accelerate vitamin C degradation, while overheating in dryers destroys heat-sensitive vitamins. Modern, well-controlled processing systems minimise these losses and improve food safety. Energy-smart fortification strategies, such as vitamin A in edible oils or iron in wheat flour, can deliver large public-health gains when paired with stable thermal and electrical systems. Reliable energy also reduces spoilage, increasing the actual nutrient availability of perishables like dairy, fruits and vegetables.

Table 12: Comparison of SEC Africa and SEC global

Food value chain	Sub product and process	Africa SEC (MJ/kg)	Global SEC (MJ/kg)
Cereals and cereal products	Wheat flour (milling)	0.073–0.101	0.06–0.09
	Maize milling	0.48–0.65	0.42–0.55
	Breakfast cereal (extrusion, baking)	11.27	~5.0
	Grain milling and baking (general)	4.32–10.8	3.6–7.2
Nuts and seeds	Drying and oil pressing	5.4–9.0	3.6–6.48
	Cashew nuts processing	13.8	8–10
Roots and tubers	Cassava gari production	0.648–1.044	0.432–0.9
	Potato or cassava snack frying	~15	14–17.3
	Tuber-based bakery products	~5.21	~5.21
Sugars and sweeteners	Sugar refining	1.8–3.6	1.08–2.52
Fruits	Fresh fruit cold chain	1.08–2.88	0.54–1.26
	Juice processing (liquid)	2.16–4.32	1.44–2.88
	Mango juice (case study)	1.12	1.0–1.5
Herbs and spices	Drying or milling	1.44–2.88	0.9–1.8
Dairy	Liquid milk and yoghurt	0.36–0.72	0.5–0.6
	Powdered milk	N/A	10.3
	Cheese making	10.08–11.52	~13.8
	Butter	3–5	3–5
	Margarine	1–2	1–2
Poultry	Eggs processing	0.72–1.8	0.54–1.08
	Poultry meat (slaughter and chilling)	0.72–2.52	0.54–4.4
	Poultry feed milling	2.88–5.4	2.16–3.6
Vegetables	Processed vegetables (canning, blanching)	1.8–5.4	1.44–3.24
	Tomato paste (sterilisation)	0.34	~4.0
	Frozen vegetables (blanch and freeze)	0.5–0.7	0.3–0.5
	Industrial dried vegetables	6–8	5–10
Beans and legumes	Drying or milling	2.88–6.48	2.16–4.32
Honey	Extraction and processing	0.5–1.5	0.5–1.0

The heat map comparison of Africa vs. Global SEC shows where African food processing is more or less energy efficient. Red bars are higher SEC in Africa than global benchmarks; green bars are lower SEC in Africa.

Figure 6: Energy efficiency gap: Africa vs global SEC



5 EE and RE integration considerations and opportunities

Energy efficiency (EE) and renewable energy (RE) integration are central to reducing Africa's food processing costs, improving reliability, and meeting sustainability goals. Evidence from the literature review, online survey, and onsite energy audits clearly shows that across cereals, nuts and seeds, dairy, vegetables, fruits, animal meats and eggs, starchy roots and tubers, and honey and spices, processors often rely on outdated, energy-intensive equipment. This is particularly acute in micro and small enterprises, where low-cost, familiar technologies are preferred, and investment capacity is limited. Yet even among larger plants, opportunities remain untapped—especially in waste heat recovery, hybrid renewable systems, and optimised process integration.

EE is the first and most cost-effective step toward lower energy bills and greater competitiveness. Improving efficiency reduces baseline demand, making renewable integration easier and more financially viable.

5.1 Energy efficiency measures

Surveyed processors and audit findings show that the gap between current practice and best practice is widest in thermal processes (drying, boiling, pasteurisation) and in motor-driven operations (milling, pumping, refrigeration). Many facilities operate with rewound motors, uninsulated boilers, and low-efficiency thermal systems. This is compounded by poor maintenance and a lack of energy monitoring.

Across value chains, upgrading to modern, energy-efficient equipment—paired with improved operational discipline—can cut energy costs by 20–50%,[16] depending on baseline inefficiencies.

5.1.1 Technologies in use vs. best practice technologies

African food processors typically rely on conventional energy technologies, which vary by value chain. These **status quo technologies** are often inefficient or labour-intensive, and several **modern alternatives remain underutilised**. Table 13 shows a breakdown by value chain, highlighting prevalent technologies versus efficient options that are not yet widely adopted.

Table 13: Technologies by value chain

Value chain	Typical technologies in use	Underutilised or best practice technologies
Cereals and cereal products	Old electric or diesel mills, manual grain cleaning, open-air or wood-fired drying	High efficiency electric mills with VFDs, well-insulated mechanical dryers, generator waste heat recovery, and solar-powered milling systems
Nuts and seeds	Wood-fired roasters, manual or dated mechanical oil presses, and inefficient grinders	High efficiency fuel or electric roasters, biomass gasifiers using shells or husks, efficient oil expellers, and variable-speed electric grinder
Dairy	Diesel or wood-fired boilers, basic chillers, no heat recovery	Solar thermal pre-heating, regenerative heat exchangers, high-efficiency chillers, biogas boilers, and phase-change cold storage
Vegetables	Open-fire boiling, rudimentary fuel-fired dryers, and sun drying	Hybrid solar-electric dryers, heat pump dryers, improved cabinet dryers, and high-insulation drying systems
Fruits and spices	Kiln dryers, manual slicing, and inefficient grinders	Hybrid solar-biomass dryers, efficient electric blowers, optimised grinders with energy-efficient motors, and heat recovery in tea or spice drying
Animal meat and eggs	Old refrigeration units, diesel generators for cold rooms, and open fire meat smoking	Biogas-fuelled boilers from slaughter waste, solar-powered cold rooms with thermal storage, and efficient smokehouses
Starchy roots and tubers	Manual or diesel graters, open-pan roasting, sun drying	Efficient rotary dryers, improved cookstoves, biomass briquetting from peels, and small-scale electric dryers
Honey and spices	Electric or gas heaters, sun drying, small inefficient grinders	Solar thermal honey warmers, insulated heating tanks, improved spice dryers, and energy-efficient grinders

[16] See survey report.

In summary, across all value chains, there is a pattern of low uptake of energy-efficient equipment. Common underutilised solutions—such as heat recovery, insulation, efficient burners, and optimised motor systems —could significantly cut energy use but are not yet common practice. The gap is especially pronounced among micro- and small processors who often stick to low-cost, familiar technologies. Meanwhile, larger processors may have more modern machinery but still miss opportunities for efficiency (e.g., waste-heat recovery from boilers or generators). This suggests a need for greater awareness and support to deploy these underused technologies. These technology gaps not only raise production costs but also limit processors' ability to maintain nutrient quality.

5.1.2 Energy efficiency interventions and best practices

Proven interventions drastically improve energy performance in food processing. Processors in African countries and beyond have implemented a range of **energy efficiency best practices**—from operational tweaks to capital upgrades—with positive results. Key interventions and practices include:

Upgrading to efficient equipment: Replacing old, inefficient machinery with modern energy-saving models is a fundamental step. Examples include high-efficiency motors and drives, improved burners or boilers, and insulated steam systems. Installing variable-frequency drives (VFDs) on motors (for pumps, mills, etc.) allows matching power to load, avoiding waste. For example, one audited maize mill reduced milling electricity use by 25% after replacing rewound motors with IE3 class motors.

Waste-heat recovery and insulation: A best practice in many industries, waste-heat recovery is underused in agri-processing. Implementing heat exchangers to capture exhaust or process heat and reuse it (for pre-heating air, water, or product) can significantly cut fuel needs. For example, a nut roasting operation could capture hot air from the roaster chimney to pre-dry the next batch of nuts. Likewise, insulating pipes, ovens, and dryers to minimise heat loss is a low-cost intervention. Processors who have added insulation and heat recovery report substantial drops in wood or fuel use. These measures are especially effective in dairy (for pasteuriser heat recovery), tea and spice drying, and any continuous heating process.

Process optimisation and good housekeeping: Many efficiency gains come from no- or low-cost changes in operations. Scheduling and load management are crucial—running equipment at optimal loads and during off-peak hours can reduce energy waste and cost. An example from Nigeria: a tomato processing firm (Tomato Jos) halved its energy costs by reorganising production schedules and eliminating idle running of equipment. Training staff to implement simple practices—like switching off machines when not in use, repairing compressed-air leaks, and keeping motors and burners well maintained—also yields energy savings. These behavioural and maintenance improvements fall under **demand-side management**, which is an important aspect of energy-smart agribusiness.

Energy audits and monitoring: Conducting periodic energy audits helps identify where energy is used and lost. By measuring specific energy consumption at each process step, companies can pinpoint "hot spots" (e.g., an inefficient dryer or an oversized generator). Several surveyed processors only realised how much energy their milling or cooling was using after a formal audit, which then informed targeted upgrades. Establishing key performance indicators (KPIs) for energy (such as kWh per tonne processed) and monitoring them over time is a best practice for continuous improvement. Some firms have started tracking these metrics and saw improvements once operators were accountable for hitting efficiency targets.

Process integration and scale optimisation: Integrating multiple processing steps or products can unlock efficiency through economies of scale and heat cascading. For instance, a multi-product plant that processes cereals plus oilseeds can use waste heat from the grain dryer to help roast seeds or use one boiler for multiple operations.

The survey found that enterprises handling multiple product categories tend to have much lower specific energy consumption (0.69 MJ/kg on average)[16] compared to single-product firms, because shared infrastructure and by-product use improve overall efficiency. Thus, encouraging co-location of processes (like pairing a spice grinder and a grain mill to utilise excess heat or power capacity) is a best practice in value-chain integration. When feasible, clustering processors (or forming cooperatives) to share energy systems—for example, a group of cassava processors sharing one high-efficiency drying facility—can overcome scale barriers that individual micro-firms face.

Efficient layout and maintenance: Optimising facility layout (shorter conveyor lengths, proper ventilation for cooling, etc.) can reduce energy demand for material handling and HVAC (heating, ventilation, air conditioning). Regular maintenance of equipment—cleaning boilers, descaling chillers, sharpening mill blades—keeps systems running at design efficiency. In West Africa, lack of maintenance is noted as a common cause of higher energy intensity (Adesanya and Schelly, 2019). Therefore, instituting preventative maintenance schedules is an essential best practice.

Implementing these interventions yields not only cost savings but also improved productivity and product quality.

5.1.3 Barriers to the adoption of efficiency measures

While the technical and economic case for energy efficiency in Africa's food processing sector is strong, the sector faces multiple obstacles that have slowed adoption. These barriers are financial, technical, informational, and institutional in nature, and they manifest differently across processor sizes and value chains. Table 14 below summarises the key barriers identified through literature review, survey findings, and energy audits, along with practical solution pathways.

A persistent **financial barrier** is the high upfront cost of modern energy-efficient equipment. Many micro and small enterprises operate on narrow margins and cannot afford to replace functional—albeit inefficient—machinery. For example, in the cereal milling chain, the difference between replacing a rewound 7.5 kW motor with a premium IE3 motor can represent more than two months of a small mill's net profit.

Larger integrated facilities, while more financially resilient, often cite long payback periods as a deterrent—especially when electricity tariffs or diesel prices fluctuate and undermine ROI projections. This challenge is amplified by **limited access to affordable finance**: commercial banks rarely offer tailored credit for energy upgrades, and donor or government financing facilities remain underpublicised and bureaucratically difficult to access.

Technical capacity constraints further slow adoption. Many small processors lack in-house technicians who can champion energy management, waste-heat recovery units, or biogas digesters. This creates a **perceived risk** that complex equipment will fail and halt production. Field interviews revealed that even when a solar dryer or high-efficiency boiler is installed, maintenance support is often absent locally—leading to downtime and eroding confidence in the technology. Without targeted training and after-sales support, uptake is unlikely to expand.

The **information gap** is equally critical. Over 70%[16] of surveyed firms were unaware of national or donor programmes supporting energy efficiency or renewables. Many underestimated the size of their own energy losses—one Ugandan dairy operator was surprised to learn from an audit that over 40%[16] of their firewood consumption could be eliminated through boiler insulation and condensate recovery. The absence of credible, context-specific performance data makes many firms risk-averse and reluctant to depart from the "tried and tested" status quo. This lack of information also obscures the nutritional impact of inefficient systems—few processors link poor insulation or outdated dryers to nutrient degradation, even though these losses disproportionately affect foods essential for combating malnutrition.

Institutional and market barriers compound these issues. High import duties on efficient equipment, lack of local spare parts, and absence of performance standards all tilt the field toward conventional technologies. For processors renting premises, the incentive to make capital improvements is low, particularly when landlords do not share energy costs. In informal processing sectors, fragmented supply chains mean energy savings do not translate directly to higher margins, reducing motivation to invest.

Finally, **scale and gender dynamics** play a role. Micro-enterprises often lack economies of scale to justify investments in efficiency measures like waste-heat recovery. Women-led processing businesses, which dominate some value chains (e.g., spices, shea, small-scale cereal processing), face additional financing and capacity building barriers, as explored further in Section 5.3.3. Without targeted measures to address these inequalities, adoption rates will remain skewed toward larger enterprises owned mainly by men.

Table 14: Barriers and solutions to energy efficiency adoption in African food processing

Value chain	Typical technologies in use	Underutilised or best practice technologies
High upfront costs	Modern high-efficiency dryers, pasteurisers, or PV systems require significant capital outlay. SMEs often operate on thin margins; survey respondents cited an inability to fund upgrades even when long-term payback is strong	Introduce concessional financing, grants, tax incentives, and equipment leasing. Promote ESCO models where service providers own and operate efficiency systems
Limited access to finance	Banks rarely lend for EE/RE projects due to perceived risk; most SMEs lack collateral. Many micro-enterprises cannot self-finance improvements	Develop tailored SME credit lines; implement PAYGO or micro-leasing for equipment; promote blended finance leveraging donor guarantees
Technical skill gaps	Lack of trained in-house engineers; poor maintenance capacity. Breakdowns of sophisticated systems can stall production	Build local technician networks; embed O&M training in all EE/RE rollouts; create mentorship links with larger processors
Low awareness and information gaps	70% of surveyed firms are unaware of incentives, donor programmes, or technical support. Limited visibility of successful EE/RE cases	Launch targeted outreach via industry associations; run demonstration projects; create national one-stop information portals
Reliability and risk perception	Fear of downtime or technology failure; preference for "known" legacy systems	Deploy hybrid systems with conventional backups; use warranties and performance guarantees; run peer-to-peer site visits
Institutional and market barriers	High import duties on EE/RE equipment; poor availability of spare parts; weak policy enforcement	Reduce import tariffs; establish local spare-parts supply chains; strengthen standards and certification
Scale constraints	Micro-processors too small to justify advanced EE/RE systems; low utilisation rates	Promote cooperative or shared facilities; cluster processors to share EE/RE infrastructure
Gender-specific barriers	Women-led processors face additional hurdles in accessing finance, training, and networks	Offer targeted financing and training for women entrepreneurs; integrate gender-sensitive design in EE/RE programmes

5.2 Renewable energy viability

Renewable energy technologies offer promising, sustainable alternatives to fossil fuels in the food processing sector across African countries south of the Sahara. Their applications span thermal processing, mechanical operations, and lighting—critical components of food value chains. Among the most commonly adopted are solar thermal systems, solar photovoltaic (PV) systems, biogas digesters, and hybrid energy systems that combine multiple technologies for enhanced reliability.

African food processors face diverse energy needs across different value chains. Tailoring renewable energy (RE) and efficiency solutions to these needs can drastically cut costs (by an estimated 25–40% on energy bills[16]) and improve reliability. This section examines energy demand characteristics and RE opportunities for key value chains—cereals, nuts and seeds, dairy, vegetables, fruits, animal meats and eggs, starchy roots and tubers, and honey and spices—noting differences between micro, small, medium, and large processors. A summary table and discussion of common barriers and enabling conditions (policy, finance, skills) are provided to inform a compelling strategy for scaling clean energy across Africa's food processing sector.

5.2.1 Solar energy applications in food processing

Solar energy can be applied in multiple ways along the agri-food chain, beyond just electricity generation. Key **applications of solar energy** for processors include:

Solar photovoltaic (electricity generation): Solar PV systems can directly power processing machinery, lighting, and cooling. This is particularly relevant in areas with unreliable grids—for example, solar PV panels coupled with batteries or a generator can keep a mill or dairy chilling unit running through outages. Solar PV is already being deployed by forward-looking processors to power milling, chilling, pumping, and lighting[16]. Systems scale from small rooftop arrays for micro-processors to 100-plus kW plants for industrial facilities. Surveyed firms with PV hybrids reported diesel savings of 30–80%,[16] particularly in off-grid or unreliable-grid contexts.

Solar thermal (process heat and drying): Solar thermal applications are very promising in agri-food processing, where heat at moderate temperatures is required. **Solar water heaters** can provide hot water or steam for processes like pasteurisation, cooking, or cleaning-in-place in dairies and abattoirs. Instead of burning wood or gas to heat water, a dairy in a sunny climate can use flat-plate or evacuated tube solar collectors to attain the temperatures needed for milk pasteurisation or cheese making. Solar thermal systems have high efficiency and zero fuel cost after installation. Additionally, **solar dryers** are an excellent application for crops and food products. There are many designs of solar dryers—from simple tent or cabinet dryers to more advanced tunnel dryers with solar air heaters. These can dry fruits, vegetables, spices, and herbs more quickly and hygienically than open-sun drying, and without the smoke or fuel expense of wood-fired dryers. For example, farmers and processors in East Africa have used solar dryers to reduce post-harvest losses in mangoes and chilli peppers (Ssemwanga et al. 2020). A study comparing open-sun drying, simple solar dryers, and polyethylene-covered solar dryers of mango and cowpea leaves found that open-sun drying caused very large losses in β-carotene (pro-vitamin A) and vitamin C (≈ 94% and 84.5% loss for mango; 58% and 84% loss for cowpea leaves). The solar-dryer variants fared better. https://pubmed.ncbi.nlm.nih.gov/15477192/

In Kenya, a pay-as-you-go model for solar-powered cold storage (and by extension, drying units with solar) has improved small farmers' incomes by 30% through reducing spoilage (Climate Action Accelerator (CAAS). (n.d.). Solar drying not only uses free energy but often yields a better-quality product (due to controlled temperatures and no contamination), which can fetch higher prices. **Solar cooling** is another thermal application: solar adsorption or absorption chillers (driven by heat from solar collectors) can provide refrigeration for milk or produce without electricity—a technology being piloted in some African countries for off-grid milk coolers (Foster et al., 2015). While solar cooling tech is still niche, simpler versions like solar ice makers or using solar PV to run conventional coolers are already proving their usefulness for fish, meat, and dairy storage in remote areas.

Agrivoltaics and integrated systems: An emerging application is agrivoltaics, where solar panels are installed above crops or processing yards, generating power while shading crops or providing covered space for drying. Though more relevant to production than processing, **agrivoltaic** setups could allow processors to generate power on-site (e.g., above a tea drying yard or above a dairy farm's cattle shed) without using extra land. The IRENA/FAO report[17] notes examples like The Gambia, where solar panels were combined with agricultural use. For processing, integrated designs might include solar roofs that both dry produce (with the heat under the roof) and carry PV panels generating power, thus utilising the solar resource for dual purposes.

5.2.2 Biogas and biomass-based energy

Biomass resources and bioenergy technologies present a huge opportunity to provide heat and power for agri-food processing in Africa. Biomass-based energy encompasses direct combustion of plant materials (wood, crop residues), use of processing by-products (shells, husks, bagasse) for heat or power, and biogas production via anaerobic digestion of organic waste. These resources are often readily available as a by-product of the value chains themselves—turning waste into energy and solving waste issues (such as disposal).

Direct biomass use and cogeneration: Many agro-processors already use biomass in basic ways (e.g., burning firewood for heat). The aim of modern integration is to use **residues more efficiently and cleanly**. A prime example is **bagasse** in sugar processing: sugar factories in countries like Kenya, Sudan, and South Africa burn bagasse in high-efficiency boilers to produce steam and electricity, enabling some sugar mills to meet nearly 100% of their own energy needs (Karekezi and Kithyoma, 2003). This concept can extend to other chains: rice mills can use rice husks as fuel, groundnut processors can burn peanut shells, coconut processors can use coconut husk and shell, etc. In Asia, rice-husk gasifiers and boilers for parboiling are common; in West Africa, this is underutilised but technically feasible. The FAO's energy-smart food chain study[18] (Sims et al. 2015) noted a rice-husk-fired boiler example that dramatically cut costs in parboiling. For palm oil mills (common in Nigeria and Ghana), fibre and shell residues are often burned for process steam.

Co-generation (simultaneous production of electricity and heat) is an ideal approach in larger agro-industries: the waste steam from power generation can be used for drying or boiling. This improves the overall efficiency to well above that of separate generation. While large-scale cogeneration is mostly limited to big industries, smaller-scale versions like a 250 kW biomass gasification plant in Uganda's Kamwenge district are being piloted to supply both electricity and heat for a cluster of agro-processors (IRENA and FAO, 2021). Such biomass gasifiers can run on maize cobs, coffee husks, or other local residues, offering a decentralised renewable power source.

[17] IRENA and FAO, 2021, *Renewable Energy and Agri-food Systems: Advancing Energy and Food Security towards Sustainable Development Goals*: https://www.spr.pe/wp-content/uploads/2021/12/IRENA_FAO_Renewables_Agrifood_2021.pdf?utm

[18] FAO and USAID, 2015, *Opportunities For Agri-Food Chains to Become Energy-Smart*: https://openknowledge.fao.org/server/api/core/bitstreams/19192e25-2993-4943-93de-58bd0fd91913/content?utm

Biogas digesters: For many food processors, biogas is a particularly attractive option to produce clean fuel for thermal needs. Digesters take organic waste (which many processing factories have in plenty) and produce methane-rich biogas that can be burned for heat or to run an engine or generator. Small-scale digesters (fixed dome, tubular bag, etc.) have been widely used on farms for manure management; now their use is extending to processing waste. For example, **cassava peels**, which are usually discarded in large quantities by cassava flour and starch producers, can be fed into a digester.

Early pilot projects in Uganda showed that cassava peels can reliably produce biogas, which, if used in a modified boiler or burner, could supply ~20% of the heat needed for drying cassava products. Similarly, a maize mill or brewery could digest some of its wastewater or organic residues to offset a portion of thermal energy. In Kenya, some medium-scale tea factories have explored using biogas from tea waste or cow manure to fuel withering and drying processes (traditionally done with wood or furnace oil) (Kibet and Letema, 2024).

Livestock-product processors (dairies, slaughterhouses) have a clear synergy: dairies can co-digest manure and wastewater to generate biogas for their boilers, and abattoirs can digest blood and paunch manure. In fact, several countries (e.g., South Africa, Kenya) have installed biogas plants at municipal abattoirs and food processing parks as a waste treatment and energy generation solution (Biogas Guidebook, n.d.; Daily Nation, 2025). IRENA notes that globally, biogas power plants are operating in sectors like sugar, cassava, and slaughterhouses (IRENA and FAO, 2021)—indicating the transferability of these practices to Africa. The main advantage is that biogas provides a clean-burning fuel (much lower emissions and no smoke compared to direct biomass burning) and can often be generated right on-site in a circular model. The digestate (spent slurry) additionally serves as organic fertiliser, creating a closed-loop with agriculture.

Biomass briquettes and pellets: Another approach gaining ground is converting loose agricultural waste into **briquettes** or **pellets** that can serve as a convenient fuel. For instance, rice husks, coffee husks, or groundnut shells can be pressed into briquettes that are used in gasifier stoves or boilers. Some entrepreneurs in West Africa produce briquettes from cassava peel and sawdust, selling them to bakeries and food processors as a sustainable wood-coal substitute. This not only gives processors a reliable fuel source but also reduces deforestation pressure from firewood. Efficient briquette-burning stoves can achieve higher burn efficiency and consistent heat output, improving processing (e.g., more uniform roasting of nuts).

Technical and financial considerations: The viability of biomass and biogas systems does depend on having a sufficient volume of feedstock and managing the logistics (collection, storage) of that feedstock. For example, a biogas digester needs a steady daily input of feedstock—seasonal processors might struggle to feed it year-round. Technically, operators need training to run digesters or biomass boilers (e.g., controlling the moisture content of biomass for gasifiers).

Financially, many of these systems have moderate paybacks because they replace ongoing fuel purchases. A digester that offsets LPG or fuelwood can save a lot over time; a study cited paybacks of 5–7 years for small digesters in food enterprises (Lauer et al., 2018). Many African countries also have government or donor programmes that subsidise biogas in agriculture, which can improve ROI (Karekezi and Kithyoma, 2003). One must also consider maintenance costs—e.g., gasifier engines can have tar buildup issues if not properly maintained, and digesters require regular feeding and sludge handling. Despite these challenges, the **co-benefits** (waste treatment, reduced emissions, fertiliser by-product) make bioenergy very attractive.

5.2.3 Hybrid systems for energy reliability

Hybrid energy systems combine renewable sources with conventional power to ensure a reliable and continuous energy supply for processing operations. In practice, hybrids address the intermittency of renewables like solar and the gaps in any single source by blending multiple inputs. For African food processors who cannot afford any significant downtime or power quality issues (imagine milk spoiling from a fridge outage, or a batch of grain burning in a mill due to a power cut), hybrids are often the most **practical solution.**

Common hybrid configurations in agro-processing include:

- **Solar PV and grid:** Where grid power is available but unreliable or expensive, adding solar PV can reduce dependence on the grid and provide backup during outages. During sunny periods, the facility runs on solar (and even exports excess to the grid if allowed), and at night or cloudy times, it automatically draws from the grid. This reduces overall energy cost and provides some resilience. The grid, in turn, ensures that if a spike in demand or prolonged bad weather occurs, the power stays on. Many surveyed processors view grid-tied solar as a straightforward choice—essentially treating the grid as a "battery" backup. Policy support like feed-in tariffs or net metering can further enhance this model, though awareness of these types of incentives is currently low among firms.

- **Solar PV and diesel generator:** This is popular in off-grid areas or where grid outages are frequent. The solar system is sized to handle average daytime loads, and a diesel generator set is on standby for peak loads or night operation. Controllers prioritise solar to minimise fuel use, kicking on the generator set only as needed. This arrangement significantly cuts diesel consumption (fuel savings of 30–60%[16] are common) and extends generator life, while guaranteeing power 24/7. For example, PSALMS Food (a processor mentioned earlier) implemented a solar-diesel hybrid and slashed energy spending by 80%[16], as the generator now runs far less. Many remote tea factories, mills, and cooling facilities in East Africa use PV-diesel hybrids to reduce the extremely high cost of running generators full-time on costly fuel.
- **Solar and generator plus battery storage:** Adding batteries to the above systems can increase the renewable fraction and further reduce generator or grid use. Batteries store excess solar in midday for use in the evening peak or overnight for critical loads like refrigeration. While batteries add cost, their prices have been dropping, and they can be vital for certain processes that need smooth power. For instance, a poultry hatchery or a flour mill might add a battery bank to ensure a stable frequency and voltage, preventing equipment damage. In hybrids, often a smaller battery bank (to cover, say, a few hours) is enough rather than sizing for multi-day autonomy, which keeps costs manageable.
- **Multisource hybrids (solar, wind, diesel, and storage):** In a few locations, processors might tap into multiple renewables. If a region has both good sun and some wind (coastal or highland areas), wind turbines can complement solar (often wind blows at night or during cloudy conditions). Small hydro, where available, can provide a steady base, augmented by solar at peak times. These multisource systems are essentially **mini-grid power plants** for agro-processing zones. For example, if a tea factory is near a river, a micro-hydro could supply nighttime power and cloudy-day power, with solar for daytime boost, and a generator only as emergency backup. Such systems can reach very high renewable penetration reliably, but are site-specific.

The key benefits of hybrids are reliability and optimised cost. Survey results[16] underscore that most processors lean towards hybrid setups to balance the trade-offs of each source. Purely renewable systems (100% solar or 100% biomass) may either be too costly (when adding storage or oversizing to handle all conditions) or too risky (if they cannot meet occasional peak or off-hour needs). Hybrids allow renewables to be used to their maximum (cutting fuel and grid usage) without jeopardising operations. From a financial standpoint, hybrids also enable staged investments—e.g., start with a generator, add some PV to cut fuel use, and later add batteries as prices drop.

Best-fit use cases: Different value chains might favour different hybrid configurations. For example, a **grain mill cooperative** might install a solar-diesel system; during harvest season, when milling is 24/7, the solar covers daytime milling and the diesel runs at night, ensuring continuous output. In less busy periods, the solar might cover nearly all milling needs. A **dairy chilling centre** might pair solar with grid: solar runs chillers by day and charges an ice bank or battery, and grid electricity (or a small generator set) maintains cooling at night. An **oilseed processor** with mechanical presses might integrate solar, but because pressing can be scheduled, they could avoid using generator set except if a storm hits for several days. Each scenario will have an optimal mix—but broadly, *solar PV hybrids are emerging as the standard* for rural industrial power in Africa.

Moreover, the presence of a backup (grid or diesel) alleviates concerns that many businesses voiced about renewable reliability. Knowing that a generator can kick in if a cloud passes or that the grid is still there at night makes processors far more comfortable investing in solar or other renewables. Hybrid controllers and power management systems make this automatic and seamless now.

Economic viability: Hybrids often prove more bankable than standalone RE because they guarantee service levels. Lenders and investors can be shown that critical loads will always be met (thanks to the backup), thus the business risk is lower. For the processor, cost savings come from reduced diesel or grid consumption. With solar producing the cheapest power (once installed), hybrids drive down the average cost per kWh. Maintenance costs for generators also drop due to fewer running hours. In some cases, if the grid is fairly reliable, the hybrid is used mainly for peak shaving and as insurance, which might lengthen payback but provides intangible benefits of resilience.

5.2.4 Potential percentage of energy needs met by renewables

Survey data[16] confirms that renewables are no longer a distant aspiration but an attainable baseline for many processors. At Nature's Nectar in Zambia, solar PV already supplies 95% of daytime power, while Kylbry in Nigeria offsets 40% of its load through rooftop arrays—averaging a 30–50% reduction in diesel spend across pilot sites.

Equally promising, two-thirds of surveyed firms rely on biomass residues such as firewood, husks and peels for process heat; early biogas trials at three tuber-drying facilities indicate that on-site anaerobic digestion can meet up to 20% of thermal needs. When these trends are projected across hybrid systems—small-scale CHP from gasified husks or solar-thermal dryers—renewables can technically cover 70–80% of off-grid processing loads, dramatically reducing both operating costs and carbon footprints.[16]

5.2.5 Geographic and climate factors affecting RE integration

The viability of different renewable energy options in agri-food processing is strongly influenced by geographic and climatic factors. Africa is a large continent with diverse climates—from the sunny Sahelian and equatorial regions to more temperate highlands—and each offers different renewable resource profiles and needs. Key factors include solar irradiance levels, availability of biomass resources, wind or hydro potential, ambient temperatures (which affect cooling needs), and alignment of climate with processing seasons.

Solar resource distribution: Fortunately, most of Africa has high solar potential. Countries like Nigeria, Uganda, Kenya, Ghana, and Zambia (which featured prominently in the survey) enjoy strong year-round sunshine, often 5–6 kWh/m² per day or more. Survey data16 confirms solar PV thrives in high-insolation regions such as Nigeria, Uganda, and Zambia—these areas can generate ample solar power for processors, making PV investments highly effective. Even within countries, certain areas are sunnier (e.g., northern Kenya vs. coastal). Processors in sunnier zones can meet more of their energy needs from solar and see faster payback.

For example, a Rwandan grain mill in the sunny eastern province might rely heavily on solar, whereas one in a cloudier highland region might need a slightly larger system or more backup. Nonetheless, Africa's overall solar map is very favourable—far more so than Europe, where solar is already widely adopted. Thus, geography broadly supports solar uptake across African agri-food value chains. The exceptions might be regions with extended rainy seasons or cloud cover (parts of Central Africa), where solar is still viable but yields are somewhat lower, and hybrid backup is more necessary.

Biomass resource availability: Biomass and residue availability vary by agricultural production patterns, which are geographically dependent. For instance, maize cobs and husks are plentiful in Kenya's Rift Valley and Nigeria's Middle Belt, offering feedstock for bioenergy in those grain-processing hubs. Cassava peels are abundant in Nigeria, Ghana, and Uganda, where cassava is heavily grown, making biogas or briquetting projects logical there. In contrast, a processor in arid Niger may have less crop residue locally and might rely more on solar or wind.

Livestock densities also vary: Kenya's highlands and Nigeria's Middle Belt have lots of dairy farms (hence manure for biogas), while other places do not. Forestry resources (for wood or charcoal) are traditionally used in forested countries like Cameroon or DRC, though unsustainably; those areas might also pivot to agri-residues, but have to manage deforestation issues. Additionally, some biomass is already in use by competing needs (cooking fuel for households, etc.), so assessing sustainable supply is key. Regions with established agro-industries (e.g., sugar belts in eSwatini or cane in Ethiopia) have built-in biomass use; new ventures can piggyback on those models.

Hydro and wind potential: While solar and biomass are the focus, certain geographies present **other** renewable opportunities. For example, in parts of East Africa (Uganda, Rwanda, Tanzania highlands), micro-hydro potential is significant due to plentiful rivers. Indeed, Uganda has piloted small hydro-powered agro-processing hubs (like the palm oil press with a hydro mini-grid in Sierra Leone, which shows the concept). Processors in mountainous or riverine areas can exploit micro-hydro for reliable power, which is especially useful in rainy seasons when solar might dip—hydro output often peaks when rainfall is high.

Wind energy is viable in coastal and semi-arid regions (e.g., parts of Kenya, Northern Nigeria, and Senegal's coast). A few farms in Kenya have installed small wind turbines to charge batteries for dairy cooling. However, wind for agro-processing remains less common due to higher complexity and site-specific nature. Still, a hybrid solar-wind system could be ideal in places like the Kenyan rift or Saharan fringes, where wind is strong at night, complementing daytime solar.

Ambient climate and processing needs: Climate influences energy needs: in hot tropical climates, cooling requirements are greater (for dairy, meat, produce)—ironically, these sunny places are well-suited for solar to run that cooling, but also mean any solar thermal cooling has a high load to meet. In cooler highland areas, cooling loads are lower, but drying foods might be harder due to humidity (potentially increasing energy needed for drying with fuel or forcing the use of solar dryers with fans). For example, a tea processor in a damp area of Rwanda might need extra energy to achieve the same drying that the sun would do easily in a drier area.

On the flip side, solar radiation may be lower in very humid or cloudy zones (like coastal West Africa during the monsoon season), requiring larger solar systems. Geographic factors also affect technology choice: e.g., geothermal energy is an option unique to the Rift Valley regions (Kenya, Ethiopia)—Kenya has explored its geothermal for agro-processing (drying pyrethrum flowers, or using geothermal heat for milk pasteurisation at scale, as done in New Zealand). Most countries lack that resource, but it can be a game-changer where present.

Infrastructure and market access: Not strictly climate, but geography affects how feasible it is to get equipment or maintain systems. Remote rural processors in, say, northern Uganda or inland Nigeria may not have easy access to solar technicians or spare parts; this can hinder uptake even if the solar resource is great. Coastal or urban-adjacent processors might more easily get service support.

Also, proximity to grid or fuel supply plays a role: ironically, areas with very weak grid or expensive diesel (e.g., far from fuel depots) make renewables more attractive economically. Many survey respondents in Nigeria and Uganda operate where grid power is erratic, thus, geography (distance from stable power centres) pushes them toward on-site renewables by necessity.

In summary, African processors should tailor renewable integration to their local geographic context. Sun-rich regions can lean heavily on solar PV or thermal; agri-rich regions can utilise abundant residues for bioenergy; places with rivers or wind can diversify with those resources. Climate also dictates demand patterns (e.g., more cooling in hot zones, more drying energy in humid zones), which in turn influence which renewables to emphasise.

The survey highlighted that both large and small firms see strong renewable potential across their diverse regions—confirming that every studied country had at least one viable renewable resource to tap. Ultimately, a location-specific mix (the "right renewables for the right place") will yield the best results. Tools like resource mapping and geo-spatial planning are useful; indeed, projects have used mapping to site solar mills in Uganda and solar pumps in Ethiopia. By considering these geographic and climatic factors in energy planning, processors and policymakers can maximise the renewable contribution efficiently and sustainably.

5.2.6 Seasonal demand shifts and implications

Agricultural processing is often a seasonal business, tied to harvest cycles and market demand spikes (e.g., festive seasons for meat). These seasonal patterns have important implications for energy management and renewable integration:

- **Harvest season peaks:** Many value chains experience a surge in processing activity post-harvest. For example, grain milling workloads peak after the main harvest (once farmers bring maize or rice to mill), and fruit drying or canning peaks when fruits ripen. During these periods, energy demand at processing facilities can spike dramatically over a few weeks or months. A cassava processor might run boilers and dryers continuously during the cassava harvest glut, then operate at low-capacity off season.

  This creates a challenge: energy systems must handle **peak loads in season** but will be under-utilised outside of it. For renewables, this means sizing and investment need careful consideration. A solar system sized to meet peak drying load in harvest season might be idle much of the off-season unless there are other uses. Similarly, a biomass boiler might run only part of the year. The **seasonal nature of some food processing operations impacts energy provision planning**—systems either need to be flexible or have alternative uses in off-peak times to be economical.

- **Renewable resource seasonality:** Some renewable resources also fluctuate seasonally. Solar radiation is generally year-round in the tropics but can have a wet vs. dry season difference (e.g., West African solar output dips in the rainy season, June–August, which might coincide with certain harvests like maize or groundnuts). If the peak processing time falls in a less sunny period, solar PV or dryers might produce less just when needed most. For instance, tea processing in East Africa peaks during rainy seasons when solar is limited; a solar dryer might not fully meet needs at that time, requiring backup heat.

  Biomass availability can be seasonal too—rice husks come after rice harvest, maize cobs after maize harvest, etc. If a processor's waste is only generated seasonally, a bioenergy system might have feedstock only part of the year (unless feedstock can be stored). **Hydro power is seasonal** with river flow (generally higher in the rainy season, lower in dry weather—which interestingly might be complementary to solar's pattern). Wind may have seasonal patterns depending on monsoons.

- **Adjusting operations to seasons:** Some processors can shift or extend their operations to mitigate seasonality. For example, rather than trying to dry all mangoes in a few weeks, a processor could invest in cold storage to spread processing over a longer period, thus smoothing energy demand. However, not all products allow this—some have to be processed fresh.

  When high-demand seasons are short, one strategy is to use hybrids or rental generators during peaks and rely on renewables for baseload and off-peak. Alternatively, excess renewable capacity during off-season can be used for other productive uses (community electricity, ice production for fishermen, etc.) to improve utilisation.

- **Energy storage and backup:** Seasonal shifts underscore the importance of storage and backup. A system that is renewable-heavy might include seasonal storage—e.g., a biogas plant that ramps up in harvest season and stores gas or power (perhaps feeding into the grid or charging batteries) to use later.

  Pumped hydro or hydrogen are large-scale ideas sometimes floated for seasonal storage, but at the processor level it is more about having backup generators or grid draw for those peak times. For instance, a rice mill could run mainly on a biomass gasifier but keep a diesel generator set for the height of the season when both the gasifier and solar PV are maxed out. **Silo capacity** for biomass can help extend fuel availability beyond harvest: if you can store enough rice husk or bagasse from the season to use year-round, your boiler can run on renewable fuel continuously.

- **Impact on economics:** Seasonal utilisation affects the economics of energy investments. If an expensive solar or biogas system is only heavily used 3 months a year, the effective cost per unit of energy saved is higher. This can be a barrier unless other value is derived in the off-season.

  One way to address this is multi-cropping or **diversification**—if a facility can process two or three different products in different seasons (many of the surveyed firms do handle multi-product operations), then the energy systems are used more continuously. For example, a processor might dry grains in one season and spices in another using the same solar dryer or biomass boiler, achieving nearly year-round use. Indeed, firms with diversified processing lines showed more stable energy consumption over the year.

- **Seasonal business models:** In some cases, mobile or modular energy solutions help. A portable solar generator or mill might be moved between communities seasonally (e.g., follow the harvest). This way, an asset is not idle—it serves multiple user groups at their peak times. Another model: leasing out excess capacity off-season. A tea factory with a micro-hydro plant could sell power to the grid or a nearby village in the off-season downtime. Similarly, an ice plant for fish (peak in certain seasons) could sell excess solar power to a grain mill in the off-season.

In practical terms, processors must plan their energy use around their production calendar. Many traditional systems, like wood firing, inherently manage this—wood is only used when needed. Renewables can do the same but need planning: **sizing, storage, and integration** are key. The FAO energy-smart report (Flammini, Sims, Bracco and Puri, 2015) observes that the seasonal nature of agri-processing influences how off-grid energy systems are designed and sized—energy planners should factor in that a plant might only run X months at full tilt.

A positive note is that for some products, the seasonality of resource and demand aligns well. For instance, **cereal drying** after harvest often happens in the dry season when solar is strongest, making solar dryers or PV-powered fans very effective then. Conversely, **tea or coffee processing** might peak in rainy or cloudy seasons but those also produce biomass waste (coffee pulp, etc.), which can be used to fuel the process in the absence of sun.

5.3 Awareness, capacity, and gender considerations

Successful integration of energy efficiency and renewable energy in food processing does not depend only on technology and economics—it also hinges on awareness, human capacity, and inclusivity. Here we address the soft factors: how aware and willing processors are to adopt new solutions, their access to information and support programmes, and the particular challenges faced by women-led enterprises in the sector. These cross-cutting considerations are crucial for ensuring that the benefits of cleaner energy reach all players and that interventions are sustainable and equitable.

5.3.1 Awareness and willingness to pay among processors

The level of awareness about energy-saving opportunities and renewable options among food processors is generally low, but is improving. Many small and medium enterprises are focused on day-to-day production and may not realise how much they could save with an efficient motor or a solar PV system, or they may harbour misconceptions about costs and reliability. The survey of African processors found that a majority had limited familiarity with specific renewable or efficiency interventions until they engaged with the study. For instance, more than 70%[16] reported low or no awareness of existing incentives or technical support for clean energy—implying that many simply are not in the loop on what is possible or available.

However, awareness is slowly growing as energy costs bite harder. In Nigeria and Ghana, for example, skyrocketing diesel and electricity prices in recent years have made energy a boardroom issue for even mid-sized agri-businesses. This pain point is driving more interest and openness to alternatives. Processors are starting to ask questions like "Can solar reduce my generator bills?" or "How can I cut wood fuel use in my ovens?"—questions that indicate a shifting mindset.

Willingness to pay for renewables or efficiency is closely tied to perceived ROI and risk. Many processors say they are willing to invest if they see a clear business case (short payback, proven technology). The survey revealed encouraging signs: several respondents indicated **willingness to pilot new models** like pay-as-you-go solar or leasing arrangements if those were offered by reliable providers. In other words, when upfront cost barriers are removed (through financing innovation), processors are quite willing to adopt renewables. For example, one Ugandan grain miller was open to leasing a solar system, as the monthly lease would be on par with their diesel expense. This illustrates that willingness is there if cash flow can be managed.

That said, willingness varies by size and context:

- **Micro and small enterprises** are often cash-strapped and risk-averse, so even if they conceptually like the idea of solar, they might be unwilling to divert scarce capital to it. Their willingness increases if external support or guarantees exist (grants, loans, or someone else taking performance risk). Some microprocessors also mention they prioritise investments that expand production (like a new grinder) over those that cut costs (like an efficient burner), unless the cost issue is acute.
- **Medium and large firms** generally have more capital and a more strategic outlook; they show a higher willingness to invest in energy improvements, especially if it aligns with corporate sustainability goals or if energy is a major cost line. A few large companies in Nigeria and Kenya have already installed substantial solar plants or energy management systems—often these are the industry leaders setting examples.

An interesting insight from Kouakou and Soro is that education levels correlate with better energy efficiency outcomes. This suggests that processors led by more educated managers might be more aware and willing to adopt modern energy solutions (Kouakou and Soro, 2022). Indeed, those who have had exposure (e.g., through training or international partners) tend to show more proactive attitudes. Partners in Food Solutions (the network behind the survey) itself plays a role in raising awareness by connecting processors to technical expertise.

In terms of willingness to pay, it is closely tied to expectations of reliability and savings. If a processor is not confident that a solar dryer will reliably dry their crops (maybe worried about weather or technical issues), they will not pay for it. Building trust via demonstration projects is key. The IRENA/FAO report highlighted that demonstration and better information can help prospective users assess viability and thus increase their willingness to adopt (IRENA and FAO, 2021). We see that once one or two businesses in a community successfully implement a renewable solution, others become much more willing to follow—a positive peer effect.

One must note that willingness to *pay* is different from willingness to *adopt if subsidised*. Many may say yes to renewables if grant-funded but are hesitant to pay full price themselves. Initiatives often need to nudge that first investment through co-financing or risk-sharing.

Encouragingly, as more success stories emerge (e.g., a mill cutting costs by 30%[16] with solar, a dairy solving its cooling issues with biogas), awareness spreads and willingness grows. The survey documented cases like PSALMS Foods cutting energy costs 80% with a solar-diesel hybrid and Tomato Jos halving costs via optimisation. Such stories, when shared, make others in the sector sit up and take notice.

In summary, awareness remains a barrier but is improving, and willingness to invest is present when the proposition is clearly beneficial and risk-mitigated. A concerted effort by industry groups, NGOs, and government can further boost awareness through workshops, case studies, and showcasing model facilities. Likewise, creating enabling conditions (like financing) will convert willingness into action. Essentially, processors want reliable, cost-saving energy—if we make it easy and credible for them, they are ready to embrace these innovations.

5.3.2 Access to information on incentives and support programmes

Access to information is a critical enabler for energy transition in the food-processing sector. There are various incentives, subsidies, and support programmes out there—from government tax breaks to donor grants and technical assistance programmes—but many processors simply are not aware of them. The survey underscored this point: **over 70%[16] of respondents had low or no awareness of government incentives, donor programmes, or utility schemes supporting renewable energy**. This information gap means opportunities go untapped.

For example, Kenya, Nigeria, Uganda, and Zambia all have introduced policies like zero import duty on solar equipment and, in some cases, tax credits for renewable energy investments. Some utilities offer net metering or feed-in tariffs for solar. There are also programmes by organisations (e.g., UN, GIZ) that provide grants or partial funding for clean energy adoption in SMEs. But if processors do not know about these, they cannot utilise them. One Nigerian processor remarked in the survey that they only learned of a federal renewable energy fund after it was closed—highlighting a communications issue.

Challenges in information access:

- Information is often scattered and does not reach the grassroots level. Policy announcements might be in conferences or workshops, gazettes, or ministry websites not frequented by business owners.
- Smaller businesses may not have the time or capacity to track government programmes or donor projects. They rely on word of mouth or industry associations, which are generally weak and sometimes fail to disseminate.
- Even when they hear of an incentive, the details (eligibility, how to apply) may be unclear, deterring usage.
- Some countries have multiple overlapping initiatives (energy efficiency standards, loans, etc.), causing confusion about what is applicable.

Improving access to information could involve:

- **One-stop portals or help desks** for SMEs on energy programmes. A centralised resource that lists all available incentives (reduced VAT on solar kits, grants for efficiency upgrades, etc.) in simple terms would be invaluable.
- **Industry associations and extension services** can play a role in circulating information. For instance, a dairy processors association can inform members about a new solar milk chiller subsidy program, ensuring wide reach.
- **Workshops and training** often double as information-sharing platforms. Government energy agencies partnering with agriculture ministries could hold regional workshops to explain what support is available and how to get it.
- **Leveraging existing networks** like Partners in Food Solutions, which already engage with many processors. These networks can disseminate information on financing facilities or technical support projects. The survey was part of such an engagement; it combined data gathering with the sharing of benchmark information and potential solutions.

The IRENA/FAO report (2021) recommends improving the **data and information base** to guide renewable investments in food systems. This includes mapping optimal sites and conducting cost-benefit analyses, but also simply making information user-friendly and accessible. When processors have accurate information on, say, a 30% capital subsidy for energy-efficient equipment, they are more likely to invest—the uncertainty is removed.

Supporting programmes awareness also ties to willingness (from Section 7.3.1): if a processor knows there is a grant covering 50% of a solar dryer cost, they become *much* more willing to consider it. Conversely, a lack of information means they assume no help is available and stick to business as usual.

Another aspect is technical information access—not just incentives but knowledge on what technologies are appropriate. Many entrepreneurs do not know where to get independent advice on energy. They might only hear sales pitches from vendors, which they may distrust. Having neutral information sources (like government energy extension or university programmes) can build confidence. Some countries have established renewable energy and energy efficiency centres (e.g., ECREEE for ECOWAS region)—these can produce guides and success stories targeted at agri-food SMEs.

In essence, bridging the information gap is low-hanging fruit: it does not require new technology or huge investment, just better communication and outreach. The payoff can be significant—even the best incentive programme has no impact if nobody knows about it. The survey's finding of such low awareness is a call to action for agencies and development partners to amplify their communications. Even simple measures like compiling case studies of local businesses that benefited from a certain programme and sharing that through radio, social media, or extension officers could increase uptake.

Finally, transparency and consistency in programmes matter. If processors see success stories and clear information, they will trust the system more. If they encounter bureaucratic hurdles or hidden conditions, word spreads and discourages others. Thus, ease of accessing not just information but the programmes themselves (streamlined application processes, etc.) will improve overall adoption rates of renewable and efficiency measures.

5.3.3 Special challenges for women-led processors

Energy access and technology adoption are not gender-neutral. Women-led enterprises in food processing face unique challenges that can make it harder for them to implement energy efficiency improvements or adopt renewable energy solutions. Women play a major role in Africa's food sector. They are estimated to produce 60–80% of food in many countries and are heavily involved in the processing of products like cereals, spices, and dried fruits (World Economic Forum, 2018). So, addressing women's specific constraints is crucial for an inclusive energy transition.

Key challenges for women-led processors include:

- **Limited access to finance and assets:** Women entrepreneurs often have less access to credit, in part due to a lack of collateral (land or property is frequently owned by men), and also due to biases in financial institutions. This makes financing energy equipment upgrades even harder for them than for their male counterparts. Without capital, they cannot invest in a solar dryer or an efficient mill. Programmes that require matching funds or loans may inadvertently sideline women-owned businesses. Additionally, women may operate smaller, home-based processing ventures with lower revenues, which struggle to accumulate investment funds. This financial gap is a major barrier to technology adoption for women-led firms.
- **Information and training gaps:** Women often have lower access to formal training or technical information channels. For cultural or practical reasons (time constraints, mobility, literacy), they might not receive the same information about new technologies or attend workshops where such solutions are discussed. The IRENA/FAO (2021) report explicitly notes that women and women-led enterprises face greater obstacles in accessing and benefiting from renewable energy in agriculture. It also emphasises that *information and training must be made accessible to women* to close this gap. If training programmes on efficient equipment or maintenance are not tailored to include women (e.g., scheduling at times they can attend, providing childcare, or specifically targeting women's groups), women-led businesses may miss out on critical capacity building.
- **Social and cultural barriers:** In some communities, there are stereotypes that high-technology or mechanical fields are "men's domain." A woman miller might find it hard to be taken seriously by a male technician or may hesitate to approach technical agencies. Field reports have noted cases where equipment suppliers will address the woman's husband instead of her, even if she owns the business (International Energy Agency [IEA] and African Organisation, n.d.). This can discourage women from engaging with technology providers or negotiating effectively. Moreover, women often shoulder a larger share of household duties, leaving them less time to experiment with new technologies or apply for programmes—energy improvements may fall low on a long list of priorities unless actively supported.

- **Scale of operations:** Many women-led processing businesses are micro or small scale (e.g., groups making spice blends, cooperatives drying fruits). As mentioned, micro-scale can mean less ability to afford efficient equipment (smaller volumes also mean savings from efficiency are smaller in absolute terms, so less incentive). Without aggregation, they face scale barriers individually. Solutions like co-operatives or group purchasing can help, but those require coordination and sometimes outside facilitation.
- **Access to networks:** Men might have better access to business networks or mentorship that shares information on innovations. Women processors may not be part of male-dominated trade associations, for instance. If energy programmes are disseminated through those networks, women can be left out. There are women entrepreneur networks and cooperatives, and leveraging those is important to ensure inclusive reach.

These challenges mean that without intentional inclusion, women-led processors could be left behind in the push for energy efficiency and renewables adoption in their food processing enterprises—exacerbating gender gaps in productivity and income. It is encouraging that major organisations recognise this: for example, IRENA/FAO recommends that the gender dimension be integrated in decision making and capacity building, ensuring women have access to information and training on new technologies.

There are emerging good practices:

- Some programmes offer **targeted financing** for women entrepreneurs (e.g., grants or lower-interest loans for women-led SMEs to get clean energy equipment). This helps overcome the collateral and capital hurdle. A good example is funding rounds by USADF, PSFU-Grow Project.
- **Training programmes for women** in energy skills are being developed. GIZ ran a "Women in the Driving Seat" programme training women in tractor and machinery operation. Similar efforts for solar technicians or energy auditors can build a cadre of women who can support their peers.
- Using **women's groups and cooperatives** as entry points. In many villages, women organise in savings groups or cooperatives for food processing. Projects that introduce, say, a solar dryer or an efficient grinder through these groups tend to have better adoption, since the women collectively manage and benefit, and social norms may more readily accept group ownership.

Additionally, since women often handle certain value chains (like traditionally, women dominate cereal processing at a small scale, or shear nut processing, etc.), focusing energy interventions on those chains will inherently benefit women. Ensuring those interventions are designed with women's input (for example, a more ergonomic, efficient stove for shea butter production) also improves success.

In the survey context, while it did not explicitly break down responses by gender, it is likely that a number of respondent businesses were women-owned (especially in categories like spices and honey, which had a few respondents). The general findings—lack of awareness, desire for training, need for financing models—are even more pronounced for women-led firms. So, the recommendations (capacity building, better information dissemination, tailored financing) apply with even greater urgency to women.

6 Cross-cutting impacts

Beyond direct economic benefits for processors, the transition to sustainable energy in food processing yields important cross-cutting impacts. Notably, there are co-benefits for climate change mitigation and nutrition or food security, as well as implications for food prices and the affordability of healthy diets. These broader impacts reinforce the rationale for promoting RE and EE in agri-food value chains.

6.1 Climate and nutrition co-benefits

6.1.1 Climate mitigation

The food processing industry's energy choices have significant climate implications. Reliance on diesel generators and inefficient biomass (firewood) contributes to greenhouse gas emissions. In fact, energy use (mostly fossil fuels) is responsible for about one-third of GHG emissions from food systems globally. Adopting renewable and efficient technologies in African agro-processing can substantially cut these emissions. Analysis suggests that shifting even 30–50% of a processor's diesel consumption to solar PV or biogas could reduce CO_2 emissions by on the order of 2,000–5,000 tonnes per year for a large facility.

At a national scale, if many such firms switch to clean power, the emissions avoided will help countries meet their climate targets (Nigeria's NDC, for example, emphasises reducing emissions from generators and improving energy efficiency). Moreover, decreasing the use of firewood and other biomass for process heat (currently dominant in many Ugandan and Nigerian SMEs) has benefits for forest conservation and local air quality. Efficient cookstoves, biomass gasifiers, or solar thermal systems can replace traditional firewood boilers, thereby lowering deforestation pressure and soot emissions. This contributes not only to climate mitigation but also to healthier ecosystems. In sum, the energy transition in agro-processing aligns with global climate action and "green growth" pathways, reducing the carbon footprint of Africa's growing food industry.

6.1.2 Climate adaptation and resilience

Improved energy systems also enhance climate resilience in food value chains. Reliable renewable power (such as solar and small hydro systems) makes processors less vulnerable to climate-related grid disruptions or fuel supply shocks. For instance, a cereal mill with its own solar hybrid system can maintain operations during grid blackouts (which may become more frequent due to extreme weather), ensuring a continuous food supply.

Additionally, some renewable solutions directly help with adaptation—e.g., using solar-powered cold storage and ice makers to preserve fish, milk, or produce in the face of rising temperatures. By cutting post-harvest losses (discussed below), these solutions make food systems more resilient to climate impacts. Finally, the circular economy aspects (like turning agro-waste to energy via biogas) reduce open waste burning and methane emissions, while providing organic fertilisers as byproducts, thereby improving soil resilience.

6.1.3 Nutrition and food security

Clean energy interventions can yield major gains in food availability and nutritional outcomes. A critical link is the reduction of post-harvest losses—especially for nutrient-rich but perishable foods. Lack of energy for drying, cooling, or processing leads to spoilage of crops that could have provided essential nutrients.

Introducing renewable-powered processing can change this. For example, solar-powered cold chain units in fruit and dairy value chains can curtail post-harvest losses by an estimated 20–30% (Shell Foundations, 2025). In Uganda and Nigeria, where post-harvest loss rates for fruits, vegetables, and tubers often reach 50% or more (BusinessDay NG, 2025), a 20–30% loss reduction means a significant increase in food available for consumption. More food makes it to market and to consumers' plates, improving food security. It also means farmers and processors retain more of their produce to sell, potentially increasing the availability of diverse foods (fruits, milk, fish, etc.) in local markets. This diversity is key for nutrition—it helps lower the risk of micronutrient deficiencies.

Improved processing and storage enabled by energy can also enhance the nutritional quality of foods. Efficient electric or solar dryers, for instance, can dehydrate fruits and vegetables quickly and hygienically, preserving vitamins that might be lost in traditional sun-drying. Likewise, better milling equipment (with consistent power) can produce higher-quality flour with improved nutrient retention (important for staples like maize flour, which may be fortified with vitamins and minerals).

A stable energy supply ensures that fortification machines, mixers, and quality control instruments run reliably, which is crucial in programmes to fortify staple foods (an area of focus for organisations like GAIN in Nigeria). In cold chains, continuous electricity keeps milk and dairy products safe and nutrient-rich over longer periods, allowing broader distribution.

Energy reliability is also foundational for food fortification programmes. Fortification equipment—mixers, premix feeders, quality-control systems—requires stable electricity. Clean energy systems help processors maintain uniform dosing, reducing the likelihood of under- or over-fortified products.

All these factors translate to improved nutrition: consumers gain access to safer, more nutritious food products year-round. Energy reliability is also foundational for food fortification programmes. Fortification equipment—mixers, premix feeders, quality-control systems—requires stable electricity. Clean energy systems help processors maintain uniform dosing, reducing the likelihood of under- or over-fortified products.

6.1.4 Public health and cooking energy

Although beyond industrial processing, it is worth noting a related co-benefit. As food processing firms adopt cleaner energy, there can be spillovers to local communities with indirect nutrition and public health gains (e.g., excess biogas from agro-waste used for community cooking fuel, or solar installations providing off-hour power to nearby clinics or homes). Reducing diesel generator use also cuts local air pollution and noise around processing sites, benefiting worker health and nearby residents. Overall, the transition creates a more sustainable food system. It feeds people while supporting climate goals and healthier diets.

6.2 Food prices and the cost of a healthy diet

Energy costs are a significant component of food processing expenses, which ultimately affect food prices for consumers. In African contexts where food prices are already high relative to incomes, reducing energy overhead can improve affordability and access to a healthy diet.

6.2.1 Reducing production costs

Introducing energy efficiency and renewables can substantially lower operating costs for processors and can indirectly support better nutrition. Survey data show that monthly energy expenditures for food SMEs ranged from about USD 1,500 up to USD 18,000 in the sample, with sectors like nuts and seeds and dairy on the high end. These energy bills (covering electricity, diesel, and biomass) contribute to the final cost of products. When companies invest in efficiency —for example, optimising loads or recovering waste heat—and switch to cheaper, renewable sources, their energy bills drop.

Case studies from Nigeria demonstrate the impact: one food company (PSALMS Foods) managed to cut its energy costs by 80% by deploying a solar–diesel hybrid system. More commonly, efficiency upgrades and RE integration can reduce energy bills by roughly 25–40%, according to the survey findings. Such savings free up working capital and can translate into lower unit costs of production. In competitive markets, cost savings often get passed through (at least partially) as lower product prices or slower price increases. Even if not immediately reflected on retail shelves, reducing energy expenditures helps processors stabilise their finances, which improves their ability to hold prices steady. This is especially relevant in staples like flour, cooking oil, or milk—if mills and dairies can cut costs, it can mitigate the price pressures on these daily foods.

6.2.2 Price stability and resilience

Renewable energy adoption also insulates food processors from the volatility of fossil fuel prices. Many Nigerian and Ugandan firms rely on diesel generators due to unreliable grids, which tie their operating costs to global oil price swings. When diesel prices spike (as seen in recent years), food production costs jump and are often passed to consumers as higher prices.

By contrast, a factory running on solar power is far less exposed to such swings. Surveyed processors noted that reduced reliance on diesel improved their competitiveness in both domestic and export markets by stabilising energy costs. In essence, cleaner energy builds resilience against external shocks—whether fuel price surges or grid outages—thereby reducing the likelihood of sudden food price hikes due to energy issues. This stability is crucial for staples and processed foods that form the core of consumers' diets.

For example, a bakery in Lagos with solar backup can maintain bread production during a grid blackout without resorting to expensive diesel, ensuring a consistent supply and pricing. On a larger scale, if numerous processors become energy-resilient, the food supply chain is less likely to experience disruption-induced scarcities that drive up prices during crises. A more energy-resilient processing sector therefore contributes to a more nutrition-resilient food system.

6.2.3 Food affordability and healthy diets

A healthy diet in Africa (one containing sufficient fruits, vegetables, protein, and micronutrients) is often expensive relative to average incomes. High processing and distribution costs are part of the reason nutrient-rich foods cost more. By lowering energy costs and losses, RE and EE adoption can improve the affordability of these foods.

Take the example of perishable foods in Nigeria: due to inadequate cold storage and processing, roughly half of fruits and vegetables are lost post-harvest (BusinessDay NG, 2025; Edenhofer et al., 2012; Shell Foundation, 2025). This massive loss inflates the market price of the portion that does reach consumers. Experts in Nigeria estimate that tackling post-harvest losses would increase food supply and "naturally…have positive implications for bringing down prices" (BusinessDay NG, 2025).

Renewable-powered cold rooms, milk chillers, and efficient preservation can help retain that other 50%, effectively doubling the supply of some foods. Greater supply tends to lower prices, making items like tomatoes, leafy greens, or milk more affordable for families—and thereby improving access to vitamins and protein.

Additionally, efficient processing can reduce the cost add-on at the processing stage. If an efficient grain dryer uses significantly less firewood than a traditional method, the cost per tonne of dried grain drops, potentially reflecting in the wholesale price.

Lower energy costs may also enable processors to **fortify or improve products** without pricing them out of reach. For example, a maize flour mill that saves money on electricity can afford to add nutrient premix or invest in quality packaging while keeping its flour price competitive. Thus, energy efficiency indirectly supports nutrition by making it viable to produce enriched, higher-quality foods at scale.

Finally, **cost of diet** studies (e.g., FAO's metrics for a "cost of a healthy diet") highlight that poorer households struggle to afford proteins and fresh produce. By reducing waste and cost in the value chain, RE and EE measures can bend the cost curve of these healthy foods. Consumers benefit through potentially lower retail prices and improved availability year-round (since cold storage allows off-season supply).

Over time, as more food processors adopt sustainable energy and become more efficient, the cumulative effect could be a more resilient food system with moderated price inflation. This would mean fewer shocks to the cost of a nutritious food basket. In summary, cleaner energy in agro-processing not only yields business savings but also contributes to more affordable, accessible, healthy diets, especially in countries like Nigeria and Uganda, where food inflation and accessibility are ongoing concerns.

7 Recommendations

Building on the survey findings and literature, this section outlines actionable measures to promote clean and efficient energy use in Africa's food processing sector. The recommendations focus on creating an enabling environment through supportive policies, innovative financing models, and capacity-building initiatives—with attention to country-specific contexts in Nigeria and Uganda within the broader African landscape.

7.1 Policy and regulations

African governments should strengthen the policy framework and incentives to accelerate renewable energy (RE) and energy efficiency (EE) adoption in agro-processing:

7.1.1 Integrate energy in sector plans

Align agriculture and energy policies so that food-processing energy needs are embedded in national strategies. For example, Uganda's action plan calls for harmonising priorities between the Energy and Agriculture ministries and integrating distributed renewable energy (DRE) and productive use into the national energy and agricultural policies. Cross-sector coordination (including private sector and civil society) should ensure that agro-industrialisation initiatives explicitly address reliable power supply and efficiency.

7.1.2 Fiscal incentives

Implement fiscal reforms to lower the cost of clean energy technologies. Nigeria has introduced VAT exemptions on a range of solar and wind power equipment, improving the economics of industrial-scale solar installations. Similarly, Uganda is moving to waive VAT and import duties on renewable energy and productive-use equipment (e.g., solar batteries) to spur rural agro-processing electrification. Governments can also consider accelerated depreciation allowances for energy-efficient or renewable assets—a policy already used in South Africa, where companies can rapidly write off clean energy investments to reduce taxable income. Such tax incentives and rebates will help agro-processors justify the upfront costs of upgrades.

7.1.3 Streamlined grid interconnection

Simplify regulations for connecting renewable systems to the grid or for on-site "captive" power generation. Lengthy and unclear interconnection processes currently hinder the adoption of solar PV in many countries. Reforms are underway—for instance, Uganda approved net metering regulations in 2024 to enable commercial-industrial facilities (like food processors) to install rooftop solar and feed excess power to the grid. This policy improves project bankability and grid reliability by allowing two-way energy flows. Other nations (e.g., Kenya) have exempted small captive plants below 1 MW from onerous licensing (Captive Renewables Africa, 2020), making it easier for factories to deploy their own generation. Clear interconnection standards and feed-in mechanisms (like net metering or feed-in tariffs for surplus power) will encourage processors to invest in renewables without fear of regulatory roadblocks.

7.1.4 Standards and labelling

Develop standards and voluntary labelling programmes to encourage efficient equipment. Governments can introduce efficiency labels for agro-processing machinery (motors, boilers, dryers, etc.) so that companies can identify high-efficiency models. Minimum energy performance standards could be phased in over time. In Nigeria and Ghana, for example, standards for motors and appliances are being discussed to remove the lowest-efficiency devices from the market. Labelling and standards, coupled with awareness campaigns, would drive a market shift toward energy-saving equipment in food processing.

7.1.5 National targets and plans

Finally, set explicit targets for renewable energy use and efficiency gains in the agro-industrial sector as part of national development plans or climate strategies.

Nigeria's Energy Transition Plan and Uganda's draft Energy Policy (2023) both recognise the role of renewables in productive sectors. By including metrics (such as percentage of agro-processors with hybrid solar systems, or reduction in diesel use in the food industry by X% by 2030) in national plans, governments can signal long-term commitment. This also ensures that initiatives like rural electrification, climate action (NDCs), and agricultural modernisation are convergent—prioritising investments in power infrastructure (grid or off-grid) for agro-processing zones and value chains.

7.2 Sustainable financing and financing mechanisms

Mobilising investment for EE and RE in food processing requires innovative financing mechanisms and partnerships. Given that high upfront costs and limited financing were identified as major barriers by processors, stakeholders should pursue models that blend funds and reduce risk:

7.2.1 Affordable credit and PAYG schemes

Improve access to finance for food SMEs to invest in EE/RE. This can include micro-loans, asset leasing, and pay-as-you-go (PAYG) options for equipment. For instance, companies in the survey expressed growing interest in leasing and PAYG models to avoid heavy upfront payments. Financial institutions (with central bank or donor support) could establish dedicated credit lines for energy-saving equipment, offering low-interest loans or hire-purchase agreements. In Nigeria, development banks and the Bank of Industry could extend such facilities, while Uganda's UECCC can expand its solar irrigation and milling financing programmes. These instruments allow processors to pay for solar panels, efficient motors, or biomass boilers over time from the energy savings realised.

7.2.2 Blended finance and guarantees

Leverage blended finance to de-risk projects. Blended finance involves combining public, donor, or climate funds with private capital to invest in sectors seen as high-risk. This approach is already being applied in Africa's clean energy and agriculture domains—for example, the Africa Renewable Energy Fund uses public-private capital to finance solar, wind, and hydro projects. Similarly, the Alliance for a Green Revolution in Africa (AGRA) has used blended finance to support agribusinesses (from farmers to processors), mixing grants with commercial investment to improve yields and value chains.

Governments and development partners should create financing facilities that provide partial risk guarantees or first-loss capital for renewable energy projects in agro-processing. Such facilities (e.g., through national green funds or the African Development Bank) can backstop local banks, encouraging them to lend to food processors for energy upgrades. Credit guarantee schemes can be particularly impactful in Nigeria, where banks often hesitate to lend to SMEs for unproven technologies—a guarantee or insurance mechanism can cover some default risk and unlock local capital.

7.2.3 Demand aggregation and bulk procurement

Facilitate collective approaches to reduce costs. Individual small processors often lack purchasing power, but by aggregating demand, they can obtain volume discounts on equipment like solar PV systems, efficient boilers, or insulation materials. Industry associations, cooperatives or programmes like Partners in Food Solutions (PFS) can form bulk-procurement consortia.

For example, a group of grain millers in Nigeria could jointly negotiate with a solar provider for multiple installations, cutting unit prices. Similarly, in Uganda, coffee or dairy cooperatives could pool funds to acquire shared processing equipment (like biomass gasifiers or solar dryers) that serve numerous members. Donors can support this by funding initial coordination and technical specs, demonstrating the viability of group purchasing.

7.2.4 Public-private partnerships (PPPs) and grants for pilots

Use catalytic capital to kick-start projects that the private sector may initially find too risky. Targeted grants or co-investments can be provided for "high-impact pilots"—e.g., installing a solar-battery system at a major dairy plant or retrofitting a cluster of cassava processors with efficient dryers. These pilots, supported by government or donor funds, act as proof of concept.

In Nigeria and Uganda, energy agencies and ministries (in partnership with programmes like GIZ or UNDP) could solicit proposals from agro-processors for clean energy pilot projects, offering matching grants or concessional loans. Risk-sharing facilities that cover a portion of project costs or guarantees during the pilot phase will attract private developers to service the agro-processing market. Once the pilots demonstrate cost savings (a 25–40% energy bill reduction was seen as achievable), it becomes easier to crowd in commercial finance for scaling.

7.2.5 Climate finance and carbon credits

Food processing firms can also tap into climate financing mechanisms. Projects that reduce greenhouse emissions (e.g., switching from diesel generators to solar, or from fuelwood to biogas) could generate carbon credits or qualify for green bonds. Nigeria's Energy Transition Plan envisages private sector participation in meeting climate targets—agro-industrial energy upgrades can be part of that.

Uganda, too, in its NDC, includes actions on energy efficiency. By packaging projects to meet climate fund criteria (such as the Green Climate Fund or Adaptation Fund), additional concessional funding can be unlocked. For example, a programme to deploy solar cold storage for fruit farmers could quantify emissions avoided and post-harvest losses reduced, and attract climate funding due to its mitigation and adaptation benefits. Blending such funds with local investments creates a win-win for financiers and food businesses.

Through these financial and collaborative models—from affordable micro-finance up to international blended funds—stakeholders can lower the hurdle of upfront costs and accelerate the adoption of sustainable energy in the agri-food industry.

7.3 Capacity building and technical support

Building human and institutional capacity is crucial for sustainable energy transition in the food processing sector. Many processors cite limited technical expertise and information as barriers. The following measures can empower companies and workers in Nigeria, Uganda, and beyond to implement and maintain EE/RE solutions:

7.3.1 Energy audits and advisory services

Launch programmes to provide subsidised energy audits for food processing companies. Energy audits systematically identify where firms can save energy (e.g., insulation needs, inefficient motors, leakages) and recommend practical improvements. Given that most SMEs lack in-house energy managers, governments or development partners should fund experts to conduct on-site audits and walkthrough assessments. For instance, as part of this project's survey follow-up, PFS and partners could deploy auditors to selected Nigerian and Ugandan factories.

The survey recommends subsidised audits and training on key performance indicators (KPIs) so that companies can continuously monitor their energy performance. Audit programmes have precedent—Senegal is implementing rice mill energy audits with GIZ support to cut costs and emissions (Global Green Growth Institute, 2025). By establishing an audit and advisory service, perhaps through national energy agencies or universities, dozens of processors per year can receive tailored recommendations. Importantly, these audits should link to financing or vendor referrals so that identified solutions (e.g., burner retrofits, solar water heaters) can be implemented.

7.3.2 Training and workforce development

Expand technical training opportunities focused on renewable energy and energy efficiency for agro-industry. This includes vocational training for technicians, engineers, and energy managers who serve the food processing sector. Uganda provides a good example by planning to integrate DRE topics into vocational curricula: partnerships between industry and technical institutes are being formed to add solar and efficient appliance training modules, producing more certified technicians to service equipment. Nigeria can similarly strengthen its technical colleges and apprenticeship programmes in areas like solar PV installation, bioenergy systems, and maintenance of efficient boilers or motors.

Additionally, short-course trainings and certifications can be offered to current employees of food companies (e.g., a certificate in energy management for factory managers). Donor-funded initiatives could run "Energy Bootcamps" where plant operators learn to optimise machine settings, manage diesel-solar hybrid systems, and track energy KPIs. The survey identified specific knowledge gaps—for example, many firms were unaware of technologies like variable-frequency drives (VFDs) or biomass gasifiers. Thus, targeted courses on these topics (for instance, a hands-on workshop on installing and using VFDs on grain mill motors) should be arranged in major agro-processing hubs. Building local expertise ensures that solutions are properly installed and maintained, reducing reliance on foreign specialists.

7.3.3 Demonstration hubs and peer learning

Encourage the creation of demonstration sites and knowledge-sharing networks. Processors are more likely to adopt new technologies after seeing them successfully implemented by peers. One approach is to establish demo projects or "learning hubs"—for example, a solar-powered maize milling centre or a biomass-fired tea drying facility that others can visit. These could be set up at existing businesses or at research institutes as pilot plants. Regular field days and exchange visits should be organised, bringing together food business owners, farm cooperatives, and energy solution providers. Facilities that show how controlled drying preserves vitamin A and C, or how reliable cold chains maintain nutrient quality in dairy, fish, and meat, can motivate adoption by linking energy upgrades to tangible nutrition gains. In Uganda, for instance, a solar cold storage unit installed for a fruit farmers' cooperative could host tours to showcase how it reduces spoilage.

Peer learning networks (possibly facilitated by NGOs or industry associations) can further spread best practices. Partners in Food Solutions itself operates on a knowledge-sharing model—this could be extended to energy management, by creating a platform where processors in Nigeria and Uganda share experiences (successes and challenges) with implementing EE and RE. Mentorship programmes can pair more advanced companies (or volunteer experts from multinationals) with local SMEs to guide them through project development and operation. Such peer support was highlighted as a need, given that many survey respondents felt "on their own" regarding energy improvements.

7.3.4 Technical assistance and after-sales support

Alongside training, ensure that companies have access to ongoing technical support. This can involve creating a roster of vetted service providers or installers in each country who can help size, install, and service clean energy systems for agro-processors. Donors and governments might sponsor technical assistance during the early stages of projects—e.g., helping a Nigerian rice mill design a solar–diesel hybrid system or advising a Ugandan grain mill on efficient oven retrofits. Quality assurance is key: partnerships with standards bureaus (like the Uganda National Bureau of Standards) can help test and certify new equipment and define metrics for quality (Uganda Bureau of Statistics [UBOS], 2025). Providing reliable maintenance services (perhaps through franchising or training local youth as solar technicians) will ensure the longevity of interventions.

By investing in human capacity and technical know-how, countries create an ecosystem that supports continuous improvement. Nigeria and Uganda can leverage existing institutions (universities, research centres, extension services) to host many of these capacity-building activities. In combination with policy and finance measures, building skills and knowledge will help break the "knowledge gap" barrier—empowering local enterprises to adopt innovations confidently and sustain them.

7.4 Key priorities for stakeholders

Delivering on the sector's clean energy potential will require coordinated action across public, private, and development actors:

- **Government and regulators**—Enact and enforce supportive policies, including fiscal incentives, streamlined licensing, efficiency standards, and integration of agro-processing energy needs into national plans and NDC commitments, while recognising that improved energy access supports food safety, reduced losses, and better nutritional quality.
- **Financial institutions**—Develop and mainstream affordable, SME-friendly financing solutions for RE and EE investments, leveraging guarantees, concessional capital, and risk-sharing mechanisms.
- **Technology and service providers**—Offer tailored, modular solutions suitable for varying enterprise sizes and capacities, backed by reliable after-sales service networks.
- **Industry associations and cooperatives**—Aggregate demand, facilitate bulk procurement, and serve as channels for information dissemination and peer learning.
- **Development partners**—Provide catalytic funding, technical assistance, and policy advisory support, ensuring inclusion of women-led enterprises and small-scale processors in all interventions.

In conclusion, Africa's food processing sector stands at a strategic inflection point. Implementing the measures identified in this study can simultaneously lower costs, enhance competitiveness, strengthen food security, and contribute to climate goals. The challenge now lies in mobilising the political will, financial resources, and coordinated partnerships necessary to translate the identified opportunities into sustained, sector-wide transformation.

8 Way forward and conclusion

8.1 Summary of findings

This study set out to assess energy use patterns, efficiency gaps, and renewable energy opportunities in Africa's food processing sector, with a focus on Nigeria and Uganda as representative contexts. The analysis, combining literature review, survey data, and targeted energy audits, has shown that the sector's energy intensity is significantly higher than global benchmarks across many value chains and measurable gains in nutrient retention and food safety due to more reliable drying, milling, and cold-chain systems. This is largely due to reliance on outdated, inefficient equipment, high dependence on diesel generators and biomass fuels, and limited adoption of operational best practices.

Energy efficiency interventions—from upgrading to high-efficiency motors and dryers, to implementing waste heat recovery and better insulation—were found to offer substantial cost savings, typically 25–40%, with payback periods that can be attractive even for SMEs. Renewable energy technologies, notably solar PV, solar thermal, biogas, and biomass gasifiers, have demonstrated strong technical viability for meeting both electrical and thermal energy needs. In hybrid configurations, these systems can reliably offset 50–80% of off-grid energy demand, reducing operational costs and improving resilience against grid instability and fuel price volatility.

The study also highlighted broader cross-cutting impacts. These include reduced greenhouse gas emissions and deforestation pressures, improved climate resilience of food systems, significant potential to cut post-harvest losses, and opportunities to improve the affordability and nutritional quality of food products. Importantly, the analysis confirmed that the most severe barriers to adoption are high upfront costs, limited access to tailored finance, low technical capacity, and poor awareness of both technology options and incentive programmes. These challenges are particularly acute for micro- and women-led enterprises.

8.2 Next steps for implementation

The findings point to an urgent need to move from diagnosis to action. Immediate priorities include:

1. **Scaling energy audits and advisory services**—Targeted, subsidised audits should be rolled out to priority value chains to provide SMEs with concrete, facility-specific action plans and connect them with financing and technology providers.
2. **Expanding demonstration and pilot projects**—Visible, context-appropriate RE and EE pilots in diverse value chains should be deployed as proof of concept, enabling peer-to-peer learning and building market confidence.
3. **Facilitating access to finance**—Development of dedicated financing products, such as asset leasing, PAYG, and blended finance facilities, is essential to overcome capital cost barriers.
4. **Integrating RE and EE into agro-industrialisation initiatives**—Energy solutions should be embedded in agricultural value chain upgrading programmes, rural industrial parks, and cooperative models to achieve economies of scale, reducing spoilage and maintaining the nutrient quality of perishables and fortified staples through more reliable drying, milling, and cold-chain systems.
5. **Building technical capacity**—Training programmes should target technicians, plant operators, and energy managers, ensuring local skills for installation, operation, and maintenance of RE and EE systems.

References

Adesanya, A. and Schelly, C. (2019). *Solar PV-diesel hybrid systems for the Nigerian private sector: An impact assessment. Energy Policy*, 132, 196–207. https://doi.org/10.1016/j.enpol.2019.05.038

Ampah, J., Ribeiro, J. X. F., Bugyei, K. A., Kumi, F., and Akowuah, J. O. (2021). *Status, challenges and prospects of food processing equipment fabricators in Ghana. Scientific African, 13*. https://www.sciencedirect.com/science/article/pii/S2468227621001472

Blonk, H., Tyszler, M., Van Paassen, M, Braconi, N., Draijer, N., and J. Van Rijn. (2023). *Agri-footprint 6 methodology report, part 2: Description of data*. www.blonksustainability.nl

Businessday NG. (2025). *Annual N3.5trn post-harvest loss swallows five-year agric budget*. https://businessday.ng/agriculture/article/annual-n3-5trn-post-harvest-loss-swallows-five-year-agric-budget/

Captive Renewables Africa. (2020). *Clean captive installations for industrial clients in Sub-Saharan Africa*. www.captiverenewables-africa.org

Center for Strategic and International Studies. (2025). *Access to finance for smallholder farmers*. https://www.csis.org/analysis/access-finance-smallholder-farmers

Climate Action Accelerator (CAAS). (n.d.). *Off-grid cold storage for farmers in Kenya*. https://www.caas-initiative.org/casestudies/caas-kenyas-off-grid-cold-storage/

Corigliano, O., and Algieri, A. (2024) *A comprehensive investigation on energy consumptions, impacts, and challenges of the food industry: Energy conversion and management: X, 23*, Article 100661, https://doi.org/10.1016/j.ecmx.2024.100661

IEA, IRENA, UNSD, World Bank, & WHO. (2025). *Tracking SDG 7: The energy progress report 2025*. https://trackingsdg7.esmap.org/downloads.

Daily Nation. (2025). *Maasai clan's abattoir spins off thriving biogas*. https://nation.africa/kenya/business/enterprise/maasai-clan-s-abattoir-spins-off-thriving-biogas-912594

Department of Forestry, Fisheries and the Environment (DFFE), United Nations Industrial Development Organization (UNIDO), and Global Environment Facility (GEF). (2021). *Biogas Guidebook for Small-to Medium-Scale Industrial Biogas Plants in South Africa*. DFFE, Republic of South Africa.

Edenhofer, O., Pichs Madruga, R., and Sokona, Y. (Eds.). (2012). *Special report on renewable energy sources and climate change mitigation: Summary for policymakers: A report of Working Group III of the IPCC and technical summary*. Intergovernmental Panel on Climate Change.

Energy Catalyst. (2025). *Equatorial Power shares lessons learned*. https://energycatalyst.ukri.org/innovator-interviews/interview-equatorial-power-shares-lessons-learned

Energy for Growth Hub (2022) *How the global energy crisis is improving the prospects of solar in Nigeria*. Accessed September 26, 2025 from: https://energyforgrowth.org/article/how-the-global-energy-crisis-is-improving-the-prospects-of-solar-in-nigeria/

Flammini, A., Sims, R., Bracco, S., and Puri, M. (2015) *Energy-Smart Food: Opportunities in the agri-Food chain*. Food and Agriculture Organization of the United Nations (FAO).

Food and Agriculture Organization of the United Nations (FAO). (1992). *Utilisation of renewable energy sources and energy-saving technologies by small-scale milk plants and collection centres*. https://www.fao.org/4/t0515e/t0515e03.htm

Foster, R., et al (2015), *Solar milk cooling: smallholder dairy farmer experience in Kenya.*

Global Green Growth Institute (GGGI), (2021) *GGGI and GIZ Partner to increase energy efficiency and access to finance (including climate finance) for rice mills in the Senegal River Valley*. Accessed August 10, 2025, from: https://gggi.org/gggi-and-giz-partner-to-increase-energy-efficiency-and-access-to-finance-including-climate-finance-for-rice-mills-in-the-senegal-river-valley/

International Renewable Energy Agency (IRENA) and Food and Agriculture Organization (FAO). (2021). *Renewable energy for agri-food systems – Towards the Sustainable Development Goals and the Paris agreement*. https://doi.org/10.4060/cb7433en

International Renewable Energy Agency (IRENA) and Food and Agriculture Organization of the United Nations (FAO). (2021). *Renewable energy and agri-food systems: Advancing energy and food security towards sustainable development goals*. https://doi.org/10.4060/cb7433en

Karekezi, S., and Kithyoma, W. (2003, June 2–4) *Renewable energy in Africa: Prospects and limits. Paper presented at The Workshop for African Energy Experts on Operationalizing the NEPAD Energy Initiative,* Novotel, Dakar, Senegal. African Energy Policy Research Network (AFREPREN) and United Nations.

Kibet, J. J. and Letema, S. (2024) *Energy use and greenhouse gas emissions in selected tea factories in Kenya. PLOS Climate, 3*(10), e0000329. https://doi.org/10.1371/journal.pclm.0000329

Kouakou, A. K., and Soro, N. (2022). *Drivers of Energy Efficiency in West African Countries. Journal of Sustainable Development 15*(5) 39. https://doi.org/10.5539/jsd.v15n5p39

Lauer, M., Hansen, J. K., Lamers, P., and Thrän, D. (2018). *Making money from waste: The economic viability of producing biogas and biomethane in the Idaho dairy industry. Applied Energy, 222*, 621–636. https://doi.org/10.1016/j.apenergy.2018.04.026

Li, Z., and Parikh, R. (2018). *Developing a unique medical-grade honey which maximises glucose oxidase activity,* https://doi.org/10.1101/411819

Linda Maryanne, O. (2022). *Sustainable energy and water use for horticultural processing by micro, small and medium enterprises in Kenya.*

Maritz, J. (2021, October 27). *Producing tomato paste in Nigeria: Tomato Jos' seven-year journey. How We Made It in Africa*. https://www.howwemadeitinafrica.com/producing-tomato-paste-in-nigeria-tomato-jos-seven-year-journey/130599

Nilsson, K., Flysjö, A., Davis, J., Sim, S., Unger, N., and Bell, S. (2010). *Comparative life cycle assessment of margarine and butter consumed in the UK, Germany and France, International Journal of Life Cycle Assessment,* 15(9), 916–926. https://doi.org/10.1007/S11367-010-0220-3

Phileo by Lesaffre, (n.d., January 8). *Energy efficiency in feed factories*, https://phileo-lesaffre.com/en/energy-efficiency-in-feed-factories/

Pillai, S. D., and Shayanfar, S. (2016). *Energy in honey processing and irradiation. In Springer Handbook of Food Industry Applications,* Springer.

Rasul, K., Bruckner, M., Mempel, F., Trsek, S., and Hertwich, E. G. (2024) *Energy input and food output: The energy imbalance across regional agrifood systems, PNAS Nexus, 3*(12). https://doi.org/10.1093/pnasnexus/pgae524

Rensource Energy (2020). *Rensource and Premium Poultry team up with Empower to deploy solar energy project to poultry farm*. https://www.prweb.com/releases/rensource-and-premium-poultry-team-up-with-empower-to-deploy-solar-energy-project-to-poultry-farm-897512518.html

Shell Foundation. (n.d.). *The 'cold chain' opportunity: Reducing postharvest losses and increasing market access for rural farmers*. https://shellfoundation.org/news/the-cold-chain-opportunity-reducing-postharvest-losses-and-increasing-market-access-for-rural-farmers/

Sims, R., Flammini, A., Puri, M., and Bracco, S. (2015) *Opportunities for agri-food chains to become energy-smart*. https://openknowledge.fao.org/handle/20.500.14283/i5125e

Ssemwanga, M., Makule, E., and Kayondo, S. I. (2020) *Performance analysis of an improved solar dryer integrated with multiple metallic solar concentrators for drying fruits, Solar Energy, 204*, 419–428. https://doi.org/10.1016/j.solener.2020.04.065

Sturm, B. and von Gersdorff, G. (2018). *Module 4.2: Drying of herbs and spices. In Sustainable processing for organic food products* [Teaching module]. https://www.susorgplus.eu/sites/default/files/training-materials-pdf/4.2_Training%20herbs_ENG.pdf

ThinkGeoEnergy (2021, February). *Kenya geothermal energy market overview*. https://www.thinkgeoenergy.com/wp-content/uploads/2021/03/Kenya-short.pdf

Uganda Bureau of Statistics (UBOS). (n.d.). *Achieving a vibrant food system with productive use of renewable energy*. https://www.ubos.org/wp-content/uploads

Winther, T., Ulsrud, K., Matinga, M., Govindan, M., and Gill, B. (2019). *Women's empowerment and electricity access: How do grid and off-grid systems enhance or restrict gender equality?* ENERGIA International Network on Gender and Sustainable Energy.

World Bank (2011). *Wood-based biomass energy development for Sub-Saharan Africa: Issues and approaches*. Accessed August 8, 2025 from: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/843941468009629566/wood-based-biomass-energy-development-for-sub-saharan-africa-issues-and-approaches

World Economic Forum (2018). *Women grow 70% of Africa's food. But have few rights over the land they tend.* https://www.weforum.org/stories/2018/03/women-farmers-food-production-land-rights/

Annex

Table 15 consolidates representative energy intensity values for different food value chains in Africa (or similar contexts), broken down by process stage. These figures draw on the latest available data (post-2020 where possible) from case studies, global benchmarks, and African industry reports as discussed above. Ranges are given where appropriate to reflect variability in processes and scales.

The table also highlights the stage that typically dominates energy consumption for each value chain (in **bold**). It is evident that **thermal processing** (heating or drying) is the dominant energy consumer for most value-added products (especially in cereals, dairy, processed foods), whereas cooling is a major driver in perishable chains (meat, fresh produce), and **primary or mechanical** energy, while significant for milling and pressing, is usually a smaller fraction of total energy except in minimally processed commodities. **Packaging** generally has the lowest share yet optimising it can still yield meaningful savings in a competitive industry with tight margins.

Observations and inferences

1. **Scale drives efficiency:**
   - **Large-scale cereal processors (>50 MTPD)** achieve very low SEC (~0.12 MJ/kg), close to global best practice.
   - **Small-scale cereal processors (1–5 MTPD)** report much higher SEC (~2.1 MJ/kg), while micro cereal-nut processors are extremely inefficient (~3.6 MJ/kg).
   - Confirms the UNIDO observation that **village mills and small bakeries in SSA are disproportionately inefficient.**
2. **Dairy:**
   - **Medium dairies (13 MTPD)** operate at ~2.7 MJ/kg, higher than global norms (1.2–2.5 MJ/kg).
   - **Small dairies (3.8 MTPD)** are more efficient (~0.74 MJ/kg), suggesting underreporting or higher reliance on manual processes.
3. **Fruits and vegetables:**
   - **Medium-scale fruit processors (~5 MTPD)** average 2.7 MJ/kg, broadly aligned with global juice/cold storage.
   - **Small fruit-spice processors (~2.5 MTPD)** are more efficient (~0.43 MJ/kg), likely due to low-tech drying.
   - **Vegetables (small, ~2 MTPD)** are extreme outliers at *22 MJ/kg*, showing the energy trap of small cold-chain or blanching units.
4. **Nuts and seeds:**
   - **Medium processors (~6 MTPD)** average ~2.0 MJ/kg, within global norms but still diesel-reliant.
5. **Honey and spices:**
   - **Micro-scale (~0.4 MTPD)** operate at ~0.55 MJ/kg, very close to benchmarks, but financially exposed due to small volumes.
6. **Roots and tubers:**
   - **Large operations (~157 MTPD)** report negligible SEC (~0.00025 MJ/kg), reflecting **missing firewood data**. True values likely align closer to 0.6–1.0 MJ/kg.
   - **Micro operators (~0.5 MTPD)** show artificially low SEC, again due to underreporting of biomass.

Table 15: Energy intensity value for different food value chains in Africa

Food value chain	Primary processing	Thermal processing	Cooling or cold chain	Packaging	Typical total
Cereals (grains)	0.2–0.4 MJ/kg (industrial milling)	**0–1.0+ MJ/kg** (drying grain if not sun-dried; thermal extruding or roasting for breakfast cereals) *(e.g., ~1269 MJ/t total for a Nigerian breakfast cereal, ~98% from steam drying pdfs. semanticscholar.org)*	Approx. 0–0.1 MJ/kg (minimal for dry grain; slight aeration or climate control in silos)	0.005–0.05 MJ/kg (bagging or bulk handling) *(often <5% of total)*	0.3 for flour (minimal drying) Up to 1.5 with drying or cooking steps
Legumes and oilseeds	0.18–0.54 MJ/kg (cleaning, dehulling, grinding) (similar to cereal milling when mechanised)	**0.10–0.50 MJ/kg** (thermal roasting for oil extraction or product enhancement) (e.g., groundnut roasting and soybean cooking for tofu)	0–0.005 MJ/kg (usually none, as products are stored dry at ambient conditions)	0.005–0.03 MJ/kg (e.g., packing dry beans and oil bottling	**0.3** (for dried legume products) Up to **0.8** if significant roasting or cooking is required
Dairy products	0.005–0.2 MJ/kg (milk collection, separation, pumping)	**0.5–2.5 MJ/kg** (thermal processing varies by product: pasteurisation on the lower end; milk powder on the upper end) *(e.g., ~1,300 MJ/t milk for milk powder evaporation researchgate.net; cheese ~13,800 MJ/t product) (Ampah et al. 2021)*	0.2–0.5 MJ/kg (milk cooling and refrigeration of dairy products) *(can be higher if long storage; Kenyan dairy ~170 MJ/t in electricity largely for cooling, researchgate.net)*	0.005–0.15 MJ/tonne (filling, packaging milk and dairy goods)	**0.8** (pasteurised milk, short storage) **2.5** (milk powder production scenario)
Meat (and poultry)	0.1–0.3 MJ/kg (slaughtering operations, cutting — mostly electrical)	0.2–0.6 MJ/kg (hot water or steam for cleaning, scalding; rendering of waste)	**0.5–2.0 MJ/kg** (chilling or freezing carcasses and meat products) (dominant in intensive operations; ~30% added energy for chilling or freezing vs slaughter-only) (Ampah et al. 2021)	0.01–0.05 MJ/kg (vacuum sealing, ancillary equipment)	**1.0** (small abattoir, minimal cold storage) **3.0** (with extensive freezing and storage)
Fish and seafood	0.05–0.15 MJ/kg (filleting or handling —often manual or small motors)	0.1–0.3 MJ/kg (if any cooking or smoking of fish is done; drying fish can be higher if not using the sun)	**1.0–3.0 MJ/kg** (ice making, chilled transport, freezing for export) *(very significant for maintaining quality)*	0.005–0.02 MJ/kg (icing or boxing fish)	**1.2** (locally consumed fresh fish with ice) **3.0** (frozen export supply chain)
Fruits and vegetables	0.1–0.3 MJ/tonne (sorting, grading—some mechanisation)	0.5–5.0 MJ/kg (processing or preservation) (huge range: e.g., ~4,200 MJ/t average for canned/dried produce (Ampah et al. 2021) >15,000 MJ/t for fried chips (Ampah et al. 2021); near 0 if minimally processed aside from washing)	**0.3–1.5 MJ/kg** (cold storage and refrigerated transport for fresh produce) *(packhouse electricity ~540–900 MJ/t including cooling)*	20–100 MJ/kg (packaging fresh produce, canning, bottling juices)	**1.0** (short-term cooled fresh market chain) **5.0** (for processed products requiring drying or concentration)
Processed foods (multi-ingredient foods, bakery, snacks, etc.)	0.1–0.3 MJ/kg (mixing, conveying—mostly electric)	**3.0–10.0 MJ/kg** (intensive cooking, baking or frying) (bread and baked goods ~5,210 MJ/t (Ampah et al. 2021); instant noodles or extruded snacks can be 7,000+ MJ/t due to frying and drying; sugar or confectionery ~6,900 MJ/t)	0–0.2 MJ/kg (some products may need cooling after baking or freezing for storage, but many are shelf-stable)	0.05–0.2 MJ/kg (high-speed packaging lines, e.g., wrapping, canning, and bottling of beverages)	**5.0** (typical bakery goods) Up to **10** (e.g., confectionery and fried snacks)

Table 16: SEC by value chain and production scale

Value chain category	Scale class	Avg production (tonnes/yr)	MTPD	SEC (MJ/kg)
Animal meat and eggs	Medium (5–50)	1,954	5.35	0.23
Animal meat and eggs, plus honey or spices	Medium (5–50)	1,950	5.34	0.00015
Beans and legumes plus fruits or vegetables	Micro (<1)	140	0.38	0.12
Cereals	Large (>50)	228,641	626.4	0.12
Cereals	Small (1–5)	991	2.72	2.09
Cereals, legumes, and nuts	Medium (5–50)	9,083	24.9	0.97
Cereals and fruits	Small (1–5)	1,401	3.84	4.94
Cereals, nuts and seeds	Micro (<1)	243	0.67	3.55
Cereals and roots, or tubers	Micro (<1)	0.3	0.001	0.26
Cereals and roots, or tubers	Micro (<1)	320	0.88	0.11
Dairy	Medium (5–50)	4,908	13.45	2.67
Dairy	Small (1–5)	1,378	3.78	0.74
Fruits	Medium (5–50)	1,937	5.31	2.72
Fruits plus honey and spices	Small (1–5)	911	2.50	0.43
Honey and spices	Micro (<1)	150	0.41	0.55
Nuts and seeds	Medium (5–50)	2,157	5.91	1.98
Roots and tubers	Large (>50)	57,500	157.5	0.00025
Roots and tubers plus fruits	Micro (<1)	175	0.48	0.02
Vegetables	Small (1–5)	741	2.03	22.22

Table 17: SEC in African processors vs. global benchmarks

Value chain	SEC (Africa, this study)	Global SEC benchmark (MJ/kg)	Source (global data)
Cereals and cereal products	1.14–4.9	0.18–0.54 (milling, wheat or flour); 3.6–7.2 (baking); ~5.0 (extrusion cereals)	FAO/OECD (2019); global food processing reviews
Dairy	~4.5	1.2–2.5 (milk processing, pasteurisation); 2.0–3.5 (cold chain)	IEA (2021), FAO dairy energy use
Fruits	~2.7	1.0–1.5 (juice extraction); 0.3–0.5 (frozen veg); 5–10 (industrial drying)	FAO/IEA food chain reports
Nuts and seeds	~3.9	3.6–6.5 (oil pressing, roasting)	Industry surveys, FAO oilseed reports
Honey and spices	~0.55	0.5–1.0 (extraction, drying)	FAO honey processing norms
Animal meat and eggs	~0.23	0.54–1.8 (egg processing); 1.0–2.5 (meat chilling and slaughter)	OECD/FAO Outlook; Naresh Kumar et al. (2018)
Roots and tubers	~0.0005* (likely underreported)	0.6–1.0 (cassava gari); 1.5–2.5 (industrial starch)	FAO cassava processing surveys
Vegetables	~22.2 (outlier)	0.3–5.0 depending on process (blanching, paste, drying, freezing)	FAO SEC reviews; CIRAD Agritrop (2023)
Mixed chains (e.g., cereals and nuts, cereals and fruits)	3.5–4.9	Aligned with higher-complexity processes (4–6 MJ/kg typical)	OECD/FAO food industry benchmarks

Benchmark observations

1. **Cereals:** African SEC is broadly **within global ranges** for basic milling or baking, but spikes to ~5 MJ/kg when combined with other processes. This reflects **inefficient diesel mills and ovens** in SSA, compared to optimised electric roller mills globally.
2. **Dairy:** At ~4.5 MJ/kg, African plants consume **1.5–2× more energy than global best practice**, due to reliance on diesel backup and fragmented cold chains.
3. **Fruits:** African processors average ~2.7 MJ/kg, slightly above global norms (1–2 MJ/kg). Inefficiencies arise from **manual operations, lack of heat recovery, and poor refrigeration performance.**
4. **Nuts and seeds:** African SEC (~3.9) aligns fairly closely with global averages, though variability suggests some processors are at the high end due to **diesel boilers and small-scale inefficiencies.**
5. **Honey and spices:** African SEC (~0.55 MJ/kg) matches global benchmarks, confirming **low-energy drying and extraction processes**. However, the financial burden is still high for small cottage processors.
6. **Animal meat and eggs:** Africa's reported SEC (~0.23 MJ/kg) is **below global benchmarks**, almost certainly due to underreporting of diesel refrigeration and generator use. In reality, meat and egg cold chains in SSA often operate at far higher energy intensities.
7. **Roots and tubers:** Reported SEC (~0.0005 MJ/kg) is **not credible**, reflecting missing firewood data. Global benchmarks (0.6–1.0 MJ/kg for gari) are more realistic, especially since traditional open-pan drying is very inefficient.
8. **Vegetables:** SEC (~22 MJ/kg) is an extreme outlier, likely reflecting **low production volumes against fixed energy use**. Global norms (0.3–5.0 MJ/kg) confirm that such values are unsustainable and highlight the vulnerability of small African processors.

Cross-cutting inference for sub-Saharan Africa

- **Diesel dependency and low efficiency** mean that African processors in dairy, cereals, fruits, and nuts consistently operate above global benchmarks.
- **Small-scale processors** (honey, spices, vegetables) face disproportionate costs, even when absolute SEC values are modest.
- **Roots and tubers** are likely under-reported but remain **heavily biomass dependent**, raising environmental and labour concerns.
- Benchmarking confirms that SSA processors are not just paying more per unit of energy but are also **less efficient per unit of output**, a dual penalty that erodes competitiveness.

Table 18: Summary table: Specific energy consumption by value chain and key unit operations

Value chain	SEC (MJ/kg or MJ/unit)	Primary energy source(s)	Highest-energy unit operation
Fruit juice	1.12 MJ/kg	Steam (80.9%), electricity	Pasteuriser (0.93 MJ/kg; 83% of SEC)
Tomato paste	0.34 MJ/kg	Diesel (98%), manual labour	Diesel-fired boilers (98% of input)
Pineapple (on-farm)	0.75 MJ/kg	Diesel (46%), labour (32%)	Field operations (diesel tractors)
Groundnut (oil mill)	0.14 MJ/kg oil	Electricity and manual labour	Oil-pressing and heating (seed crushing)
Groundnut (processing)	8.54 MJ/kg nuts	Fuelwood (75%), diesel (10%)	Fuelwood-fired dryers
Millet (farming)	2–6 GJ/ha (per Mg)	Diesel, animal draft, manual	Tillage and weeding (25–40% of TEI)
Poultry	17–50 MJ/1000 birds	Electricity (motors) and steam	Scalding and defeathering (≈ 44% of SEC)
Sausages	28.3 kJ/kg	Electricity and oven gas (40%)	Oven or gas heating
Milk (Brazil audit)	128 MWh steam/day	Wood boilers (94% thermal)	Steam generation and pasteurisation
Milk (Lagos study)	13.7–22.3 GWh loss/yr	Diesel generators vs. grid	On-site diesel generator inefficiencies
Dairy (Fan Milk Plc)	0.66–0.70 MJ/L	Diesel (75%), grid	Diesel backup gen. (Q3 peaks)
Fruit and veg (Poland)	4.7–24.3 GJ/Mg	Coal-equivalent (heat and electricity)	Freezing and thermal preserves lines

Research question: Energy efficiency and renewable energy study

(Proposed research questions guiding the literature review, audits, and analysis)

Objective 1: Energy consumption patterns and point of use

(Aligns with literature review, audits, and energy use analysis).

1. **Metrics and benchmarks:**
   - What are the common energy consumption metrics (e.g., kWh/Kg) for food processing industries (e.g., fortified staples, dairy, nuts or seeds) in Africa, and how do they compare to global benchmarks?
   - What is the average energy consumed per finished product across various food value chains (e.g., cereals, poultry, edible oils) in Africa, and how does this compare to global standards?
2. **Energy sources and distribution:**
   - What are the primary energy sources (e.g., grid electricity, diesel generators, biomass, solar) used in food processing operations, and what percentage of total energy do they contribute? Disaggregate by size of operations.
   - How do energy sources vary by food product category and processor size (SMEs vs. large-scale)? Small scale 1–10 MT/day, medium scale 10–50 MT/day, large scale more than 50 MT/day.
3. **Operational patterns and inefficiencies:**
   - How does energy consumption vary across different stages of production (e.g., drying, milling, refrigeration, packaging)? Our ability to model the energy utilisation by unit operations (drying, canning, mixing, grinding, etc) will allow us to project energy usage across other processes outside of this study.
   - Which processing stages or equipment (e.g., heat-intensive dryers, electric mills) have the highest energy consumption for heat and electricity?
   - What operational inefficiencies (e.g., outdated equipment, poor insulation, lack of automation) contribute to energy waste in small- to medium-scale processors?
   - How do energy-related productivity losses (e.g., outages) impact output volume, quality, and timelines in food processing?
4. **Cost and reliability:**
   - What is the average monthly energy cost for facilities, and how does this compare to total operational expenses? What percentage of the product cost does energy account for?
   - How does reliance on diesel generators due to grid instability impact profitability? By extension, carbon emissions?
   - How frequently do power outages or fuel shortages disrupt operations, and what backup systems (e.g., generators, batteries) are used?
5. **Seasonal and performance tracking:**
   - Are there seasonal variations in energy demand (e.g., peak harvest periods), and how are they managed?
   - Do facilities track energy consumption indicators or KPIs (e.g., kWh/kg) to enable continuous improvement?

Objective 2: Energy efficiency and renewable energy opportunities

(Guides the identification of improvements and renewable integration).

1. **Efficiency measures:**
   - What energy-efficient technologies (e.g., waste heat recovery, high-efficiency dryers) are underutilised in Africa's food processing sectors?
   - What barriers (e.g., high upfront costs, lack of technical expertise, financing) prevent the adoption of energy-efficient technologies?
2. **Renewable energy viability:**
   - Which renewable energy solutions (e.g., solar PV, biogas, hybrid systems) are most technically and financially viable for specific value chains?
   - What percentage of energy needs could realistically be met by renewables without compromising production?
   - How do geographic and climatic factors (e.g., solar irradiance, biomass availability) influence renewable energy feasibility in target countries like Nigeria and Uganda?

3. **Awareness and support:**
   - What is the current level of awareness, interest, and willingness to pay (WTP) for energy-efficient and renewable technologies among processors?
   - Are processors aware of government or development partner initiatives supporting renewable energy adoption?
   - Do women running food processing businesses face any special problems with getting affordable and reliable energy?

Objective 3: Feasibility and co it analysis

(Informs technical, financial, and operational assessments).

1. **Financial viability:**
   - Have food processors considered renewable energy in the past? What type? What is holding them back from investing in renewable energy?
   - What are the average payback periods, IRR, and ROI that are largely acceptable among food processing industries to adopt solar or biogas RE systems?
   - How do upfront costs, maintenance requirements, and financing barriers affect renewable energy adoption among SMEs?
   - What is the average current cost of solutions available in the market?
2. **Risk and infrastructure:**
   - What risks (e.g., technology reliability, regulatory changes) concern processors most about renewable energy adoption?
   - Would facilities prioritise hybrid systems (e.g., solar–grid) over standalone renewables? Why or why not?
   - How much land or roof area is available for renewable energy installations (e.g., solar panels, biogas digesters)?
3. **Business models:**
   - Who are the renewable energy suppliers with viable solutions in these two markets? What is the most common solution available?
   - What existing or new financial models (e.g., leasing, pay-as-you-go) could reduce risks for processors transitioning to renewables?

Objective 4: Actionable recommendations

(Supports policy, strategy, and partnership interventions)

1. **Policy and incentives:**
   - How do existing energy policies (e.g., tax breaks, grid-access rules) support or hinder renewable energy adoption in food processing?
   - What regulatory reforms (e.g., subsidies, loan guarantees) could accelerate uptake of energy-efficient technologies?
2. **Financial and collaborative models:**
   - Which financial models (e.g., microloans, grants) would make energy efficiency and renewable energy systems more accessible?
   - How could collaboration with utilities, development partners, or industry associations improve energy access and affordability?
3. **Capacity building:**
   - What training or technical support (e.g., staff upskilling, energy audits) is needed to implement energy management strategies.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