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TECH TRENDS IN ENERGY ACCESS:

ASSESSING THE SOLAR DRYER MARKET

Source: Raheja Solar Food Processing

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AUTHORS

This market summary was authored by Liya Bensy Thomas and Jakub Vrba from Energy Saving Trust, along with Isaiah Ouma Omolo and Catherine Kilelu from African Centre for Technology Studies (ACTS).

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DISCLAIMER

This market summary focuses on East Africa, specifically Kenya, Uganda, and Tanzania, due to the availability of data from these countries, enabling us to offer more detailed and reliable insights. Additionally, we have included data from India, which allows for some comparative analysis.

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Contact: info@efficiencyforaccess.org

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Greenhouse solar dryer with a parabola dome, Thailand
Source: Montiannoowong, Getty Images, 2020

SOLAR DRYER MARKET AT A GLANCE

Globally, about 14% of food produced[1] - amounting to USD 400 billion annually[2] - is lost post-harvest before reaching retail. In low- and middle-income countries (LMICs), these losses stem from multiple factors, including adverse climatic conditions, poor farming practices, improper handling during harvest and transport, inadequate storage facilities, pest infestation and limited access to markets.

Drying can address some of these issues by extending the shelf life of produce, making it lighter and more compact for easier storage and transport, and protecting it from spoilage, all while retaining its nutritional and market value.

In LMICs, conventional open sun drying is widely practised for food preservation. However, produce left to dry in the open is vulnerable to external factors such as contamination from birds, rodents, dust and even unexpected rains, all of which can affect product quality[3]. Adopting controlled drying systems can significantly reduce these risks. Appropriately managed dry chains[i] offer a cost-effective solution that can prevent roughly 25% of food loss at farm level in LMICs without requiring expensive infrastructure[4].

KEY FINDINGS

- Demand for solar dryers is growing, particularly in agricultural regions and among farmer cooperatives that receive financial support from governments or grants from donors to purchase solar dryers.
- Solar dryer demand is significantly driven by the growing market for dried food products among health-conscious consumers who are willing to pay a price premium.
- Solar dryers retain higher levels of nutrients in dried produce and yield higher prices in local and export markets, especially during an off-season.

i. Dry chain refers to the process of keeping perishable products dry from post-harvest to storage and distribution to prevent spoilage, pest infestations, and quality degradation. This involves effective drying and the use of moisture-proof packaging to maintain optimal conditions throughout the supply chain.

KEY FINDINGS

The high cost of solar dryers remains a major barrier for many farmers. For example, in Kenya, the price of a cabinet dryer is around 75% of a typical farmers' monthly income[5].

In East Africa, a lack of standards and regulations has led to the sale of poorly designed, substandard solar dryers.

Drying-as-a-service is an emerging business model in East Africa and India. However, it is only effective when there is a buy-back assurance[ii] given to farmers for their dried products.

CALL TO ACTION

Increase investments in Research and Development to drive innovation and advancements in solar drying technology.

Establish regulations to encourage rigorous testing to help create standardised, efficient and affordable solar dryer designs.

Align solar drying with adaptable, demand-focused business models to address both market access challenges and financial sustainability.

Invest in upskilling local technicians and manufacturers to guarantee a steady supply of high-quality, functioning, efficient solar dryers in the market.

Integrate solar drying technology into agricultural policy initiatives as a cost-effective solution to reduce post-harvest losses and enhance income while ensuring food safety.

ii. Buy-back assurance is the guarantee provided by the service provider (a cooperative or food processing company) to purchase the dried produce at a predetermined price. This arrangement ensures that farmers have a reliable market for their dried products.

Tunnel solar dryers designed by Raheja Solar Food Processing in India
Source: Raheja Solar Food Processing

SOLAR DRYER CLASSIFICATION

SOLAR DRYER CLASSIFICATION

Solar dryers can be classified based on two main factors: how the drying system collects and uses sunlight to generate heat (direct, indirect, mixed-mode, and hybrid solar dryers), and how heated air moves through the drying chamber (natural and forced convection).

Natural convection dryers use the density difference between hot and ambient air to facilitate airflow. Hot air rises naturally and circulates around the drying chamber, removing moisture from the food products. **Forced convection dryers** use fans to actively circulate hot air throughout the drying chamber, ensuring uniform drying and faster moisture removal - often reducing drying time by up to three times[6]. These fans are often powered by photovoltaic (PV) panels in solar powered dryers.

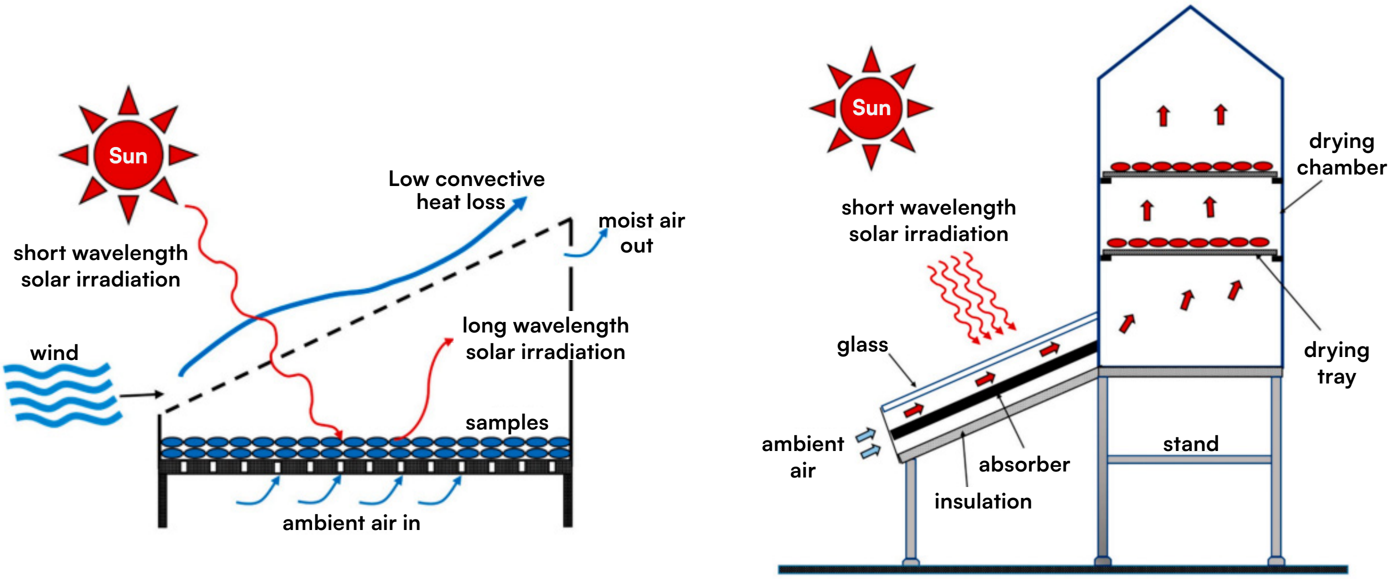
In this market summary, we focus on **indirect, mixed-mode and hybrid solar dryers.**

In an **indirect solar dryer**, air in the drying chamber is heated by solar radiation absorbed through solar collectors, with the drying chamber set up with trays. This differs from direct solar dryers, where food is directly exposed to sunlight (see Figure 1). Indirect solar dryers offer better control over drying conditions, minimising the impact of fluctuating relative humidity and temperatures - common challenges in direct solar drying. Indirect solar dryers are more prevalent in the formal market because they prevent direct exposure of food to solar radiation, reducing the risk of discolouration and nutrient loss.

Table 1: Types of indirect solar dryers: Capacities, Benefits, and Limitations

TYPE	TOTAL DRYING CAPACITY	PROS	CONS	TECHNOLOGY MATURITY	TEMPERATURE RANGE
Cabinet solar dryer (indirect solar dryer)	40-100 kg	• Low cost • Appropriate for small-scale use	• Limited capacity • Less uniform drying	Mature	60-80°C
Tunnel solar dryer (mixed-mode dryer)	100-500 kg	• Uniform drying • High capacity	• Expensive • Requires more space	Mature	30-60°C
Greenhouse solar dryer (mixed-mode dryer)	100 kg to 2 tons	• Large capacity • Easy management • Walk-in structure	• Expensive	Mature	45-60°C
Hybrid solar dryer	40-500kg	• Effective during low sunlight periods • Nighttime drying capability[iii]	• Expensive • High operational cost	Emerging	45-60°C (daytime); +10-15°C (boost)

Figure 1: Illustration of a direct solar dryer (left) and an indirect solar dryer (right)
Source: EL-Mesery et al., 2022[7]



iii. Hybrid solar dryers can continue drying during the night with supplement heat, but drying efficiency tapers off gradually during the night. It does not maintain daytime drying levels.

i. A **cabinet solar dryer** is a type of indirect solar dryer with an enclosed, box-like design. It consists of two main parts: a drying chamber and a heating chamber (see Figure 2). The drying chamber contains multiple layers of trays arranged to allow products to be laid out in a thin layer for drying. In the heating chamber, air is heated by solar collectors[iv] made from materials that efficiently absorb and convert sunlight into heat. The chimney ensures continuous air flow.

ii. Another type of indirect solar dryer includes a heat storage system[v]. This system uses materials like water, thermal oil, rocks and phase change materials (such as paraffin) to capture and retain thermal energy. This allows the dryer to operate for longer periods, even when sunlight is unavailable.

Indirect solar dryers, such as cabinet dryers, are best suited to dry small to medium batches, typically handling between 40 to 100 kg of wet produce (see Table 1).

Figure 2: A cabinet solar dryer with natural convection
Source: African Natural Products

Traditionally, these dryers were made of wood. Modern designs now use food grade materials such as galvanised iron and stainless steel. Wooden cabinet dryers remain popular due to their lower initial cost but require more maintenance.

For example, wooden trays need replacement every two years due to potential damage, which can lead to fungus and mould infestation on the food products, making them unsuitable for export markets.

Mixed-mode dryers combine features of both direct and indirect solar dryers. Products are heated by the direct absorption of solar radiation and by heated air from the solar collector.

i. **Solar tunnel dryers** are an advanced type of mixed-mode dryer with a long, tunnel-like structure covered with an ultraviolet (UV)-treated plastic foil for durability, typically lasting three to four years. The dryer is divided into two sections: the solar collector (preheating chamber) and the drying zone (see Figure 3). The tunnel is designed to trap solar energy efficiently, with transparent walls allowing for uniform exposure of the crop to heated air[8].

In the solar collector, temperatures reach up to 70-80°C. Some tunnel dryers use forced convection, with a blower at one end drawing in air and circulating it, while the other end serves as an outlet for moist air. This setup allows for faster, more even drying. Tunnel dryers typically have a higher capacity than cabinet dryers, with an average capacity of around 500 kg, which makes them suitable for medium to large-scale operations.

To maintain effective drying conditions, many tunnel dryers are equipped with systems to maintain a constant airflow velocity. This consistency ensures the air moves at an optimal rate, allowing it to heat up sufficiently, dry food effectively, and prevent moisture formation.

iv. Solar collector is a sheet of metal, painted black, placed at an angle in a large shallow box with glass top such that the air between the sheet of metal and glass is heated and allowed to flow into the drying chamber.

v. Unlike cabinet dryers, where only the top tray gets direct radiation. The transparent walls and trays of tunnel dryers allows for a more uniform exposure to heated air compared to cabinet dryers.

Figure 3: A tunnel solar dryer designed by Taylormade Solar Solutions in India
Source: Taylormade Solar Solutions Pvt Ltd

Figure 4: Greenhouse solar dryers constructed in India
Source: Raheja Solar Food Processing

ii. **Greenhouse solar dryers** are another type of mixed-mode dryer. These are larger, walk-in structures designed for easy placement and management of drying materials, with capacities ranging from 100 kg to up to two tons. They feature a flexible but rigid roof, often made of polycarbonate sheets[vi]. The roof and walls are often constructed from polyvinyl chloride (PVC) films, a versatile thermoplastic polymer, that absorbs more solar radiation, enhancing drying efficiency (see Figure 4). Like tunnel dryers, some greenhouse dryers use forced convection to improve air circulation and drying efficiency, and some are equipped with PV panels. The walk-in design allows for easy management of larger quantities of material, making greenhouse dryers suitable for larger-scale commercial drying.

Hybrid solar dryers are designed to address the inefficiency of solar dryers during low sunlight, cloudy or rainy days, and nighttime, by maintaining the temperature in the drying chamber with heat produced by burning biomass or biogas (see Case Study One). During the day, the average temperature inside a greenhouse drying chamber typically range between 45-50°C, reaching up to 60°C[vii] on particularly hot days.

When outside temperatures drop to 15°C-20°C, hybrid solar dryers can increase the drying chamber temperature by 10-15 degrees[9] during the day and five degrees at night. Though efficient, hybrid dryers are expensive and mostly suitable for commercial activities.

The latest innovation in hybrid solar dryers combines a heat pump dryer with PV panels and a small battery storage system. This setup allows energy to be stored in batteries for nighttime drying, eliminating the need for traditional thermal or chemical storage methods. While storing energy in batteries is generally more expensive per kilowatt-hour, the heat pump offers a significant advantage by amplifying the stored electrical energy by a factor of three to five.

Although PV systems are less efficient at energy conversion, their cost per square metre has decreased significantly, making them economically competitive with traditional thermal collection systems. PV systems also have the potential to break even when comparing the energy collected per capital investment. While conventional air collectors are cheaper, they are more difficult to integrate with large-scale thermal storage, and too complex to scale for high-power applications.

A greenhouse solar dryer with forced convection drying fish in Thailand
Source: Venusvi, Getty Images, 2020,

vi. These sheets are more durable and can withstand monsoons and extreme weather, typically lasting around 3-4 years, though prolonged exposure to radiation can sometimes cause the material to turn yellowish, reducing its effectiveness.
vii. This temperature varies based on geographical location.

SOLAR DRYER EFFICIENCY OPTIMISATION

Solar dryers are more efficient and hygienic than drying produce in the open sun. For instance, when drying pineapples and mangoes at 26.8°C and 26.7% humidity, open sun drying takes 16 hours. In contrast, solar dryers can dry the same products within six to nine hours at a higher temperature (40°C)[10].

The efficiency of a solar dryer depends on its drying rate, which is measured by the moisture content and weight of the products before drying, as well as the time it takes to reach the recommended dried conditions. The drying rate and performance of any solar dryer are significantly influenced by several factors, including solar Daily Normal Irradiance (DNI)[viii] and the following:

- **Shape and orientation:** Solar dryers are normally oriented to maximise the capture of available solar irradiation. An east-west orientation is recommended to maximise sunlight irradiation into the dryer throughout the year. A shape that minimises shading and maximises the surface area exposed to the sun, such as dome or arch, is preferred.

- **Heat losses and cover material:** The choice of the cover is guided by cost, the need for long-term ultraviolet stability, strength, durability, high heat retention, low vapour condensation, and high light transmittance.

  Thin poly materials commonly used in greenhouses typically have a low thermal resistance (R-value), meaning they do not retain heat well. This leads to significant heat loss, making it difficult to consistently maintain high temperatures within the dryer. While polycarbonate and glass offer better thermal properties, UV-stabilised thin films with a thickness of 200 microns are often preferred for their cost-effectiveness.

- **Radiation retention and ventilation:** Proper ventilation significantly influences temperature and moisture control. Large ventilation reduces the maximum achievable temperature within the greenhouse, and very small ventilation allows high temperatures, but results in poor moisture removal, which in turn hinders drying. Poly materials commonly used for greenhouses are thin and have a low R-value. This results in significant heat loss, making it hard to maintain high temperatures consistently.

The overall effectiveness and efficiency of a solar dryer depends on its design, capacity, and the specific needs of the operation. Cabinet dryers are suitable for smaller batches, while tunnel and greenhouse dryers are more appropriate for larger-scale operations. The choice of dryer should align with production volume and business requirements.

Tomatoes drying in a greenhouse solar dryer, India
Source: Raheja Solar Food Processing

viii. DNI refers to the amount of solar radiation received per unit area, measured in kilowatt-hours per square meter per day ($kWh/m^2/day$) which is dependent on the time of the year, weather conditions and geographical location.

Training on drying vegetables in a greenhouse solar dryer, India
Source: Raheja Solar Food Processing

MARKET DYNAMICS AND CONSUMER CHOICES

MARKET MATURITY AND DEVELOPMENT

Solar dryers are an evolving technology, offering a competitive alternative to traditional open sun drying practices. While the market for solar dryers is still developing, there is a gradual increase in maturity, driven by growing awareness and demand.

In **Kenya**, there are signs of increasing adoption of solar drying technology. The initial demand was driven largely by government or donor-funded projects between 2015 and 2017. During this period, there was a significant push for solar dryers, with manufacturers selling around 100 units per year[ix]. This surge in demand was fuelled by government financial support and awareness programmes. However, the implementation of these initiatives has been uneven, with efforts concentrated more in certain counties. Most of the dryers installed through these government initiatives have been in Eastern, Central, Western and Lake regions. For example, mango farmers in Kitui County were provided with 18 solar dryers through a donor initiative, while a food resilience programme in Western Kenya provided solar dryers to fishers to dry small fish hygienically. These programmes also encouraged small-scale farmers[x] to form cooperatives[xi] to access the solar dryers. The cooperative structure helped the farmers to pool resources, reduce losses and manage costs more effectively.

After the government projects ended, the demand for solar dryers in Kenya has declined, and many of the farmer cooperatives are no longer active. Currently, manufacturers are selling fewer than 50 units annually, a sharp decrease from the initial phase[xii]. This reduction can be attributed to the **lack of continued government support** and concerns over the quality and performance of some of the dryers available in the market[xiii].

Despite this overall decline, there is a consistent interest in solar dryers among a subset of farmers and farmer cooperatives who observed the economic benefits reaped by early adopters. This interest is primarily driven by the potential for value addition and higher income from dried produce, particularly for export markets in North America, Europe, and Asia.

In recent years, there has been a **growing demand for effective greenhouse hybrid dryers** among larger farmers and agro-processors aiming to produce high-quality dried products that meet export standards. Similarly, smaller enterprises have emerged in the market, who are venturing into drying and processing nutritious products, such as composite flours made from various dried roots and tubers mixed with seeds[11].

Figure 5: Silver cyprinids being dried in solar tent dryer installed under the NutriFish project in Kampala, Uganda
Source: NutriFish project

ix. Erastus Matete, Interview by Liya Bensy Thomas, May 16, 2024
x.Farmers with fragmented lands and have a total land between 0.5 to 3 acres. Not practising mono-cropping but planting multiple crops to reduce risk.
xi. Minimum number of members in a farmer cooperative in Kenya is 10 and can go up to 500. Each cooperative is registered as a business who can market their dried products in the local and export market after being certified by the Kenya Bureau of Standards (KEBS).
xii. Erastus Matete, Interview by Liya Bensy Thomas, May 16, 2024
xiii, Due to the lack of standards, there are local manufacturers constructing cheaper versions with lower performance — inconsistent temperatures and high moisture levels.

In **Uganda**, demand for solar dryers is steadily growing[xiv], but remains concentrated in certain regions. Many solar dryers are being installed around Kampala and the Lake Victoria region, primarily for drying small fish such as silver cyprinids (locally called silverfish). Due to the scarcity of locally available materials, high-quality dryers built with food-grade materials are often imported from Kenya. This makes solar dryers relatively expensive in Uganda, leaving farmers to opt for locally made wooden cabinet and tent dryers.

Most solar dryers in Uganda are used by individual small-scale farmers and farmer cooperatives looking to establish themselves as small and medium-sized enterprises (SMEs) to commercially sell their dried products in the export market, as domestic demand remains low. However, with the rising health-conscious middle-class population, demand for dried products is likely to increase within Uganda in the coming years. Recognising this potential, **the government has begun raising awareness about the dried goods value chain**. For instance, the National Agriculture Research Organisation in Uganda is exploring ways to integrate crops other than fruits and vegetables such as cassava and coffee into this value chain[xv].

In **Tanzania**, the use of solar dryers is concentrated around the Lake Victoria region, similar to Uganda. Users in this area have increasingly shifted from traditional open sun drying to solar dryers to reduce contamination and quality issues associated with drying fish in the open. This shift is driven by the need to improve the quality and hygiene of dried fish.

There is also growing but gradual demand from agro-processors for drying maize, grains, oilseeds like sunflower, and vegetables. These commercial ventures typically purchase fresh produce from farmers at lower prices, dry it, and then target the export market. However, the **availability of drying technologies in Tanzania remains limited**. Many commercial agro-processing units rely on electric dryers[xvi] imported from countries like China, which are costly due to high import tariffs and the substantial electricity expenses associated with operating such energy-intensive technology. Due to these market limitations, adoption of solar dryers remains low, and many farmers in rural Tanzania still rely on traditional open sun drying methods for grains and agricultural produce.

In **India**, the adoption of solar dryers is gaining momentum, particularly among farmers and agro-processors influenced by factors similar to those driving demand in East African countries outlined above. As in Tanzania and Uganda, where specific regions have embraced solar drying, India shows **regional variations in solar dryer adoption**. States with significant agricultural output, such as Gujarat, Maharashtra, and Punjab, are witnessing increased interest in solar drying technologies. Farmers in these areas are shifting from traditional drying methods to solar dryers to enhance product quality and secure better market prices. Popular dried products include fruits and vegetables like tomatoes, potatoes, onions, okra, ginger, and garlic, as well as spices like turmeric and chillies, alongside pulses and grains.

Overall, the market for solar dryers is poised for expansion in East Africa and India, driven by the demand for high-quality, safe and nutrient-rich dried products in the export market, as well as growing demand in the domestic market.

Figure 6: Onions dried by a farmer-owned agro-processing enterprise in a greenhouse dryer in Maharashtra, India
Source: Raheja Solar Food Processing

xiv. These dryers are often used to dry fruits like pineapples, sweet banana and mangoes and small fish.

xv. Alphonse Candia, Interview by Liya Bensy Thomas, May 14, 2024

xvi. Unlike solar dryers that depend on solar irradiation, electrical dryers use electric heating elements or heat pumps to produce the required heat for drying, ensuring consistent drying conditions regardless of weather. Electrical dryers are more expensive than solar dryers, with price ranging from $ 1000 to $ 50,000+

MARKET POTENTIAL

Success stories from early adopters are sparking a ripple effect among farmers, raising awareness of the higher economic returns from selling dried products.

High-value dried products like mangoes[xvii] can sell for four to five times the price of fresh mangoes in local markets during the off-season, with even higher profits in the export market[xviii]. The seasonal price of 5 kg of fresh mangoes is about 500 KES (USD $4). By drying mangoes during peak harvest, farmers can reduce losses from spoilage and earn significantly more during off-season, especially in export markets where demand and prices are higher.

There is also strong demand for dried vegetables and spices in European, American, Middle Eastern and Asian countries. In Kenya, agro-processors are willing to pay up to USD $3,000 through credit to acquire a solar dryer for commercial use[12].

In the domestic markets in Kenya, Uganda, and Tanzania, dried products are mainly purchased by upper-middle-class consumers, limiting demand to high-end supermarkets. Similarly, in India, primary consumers include the hotel and catering industries and high-end supermarkets, with a large share of dried products being exported.

Growth in solar dryer manufacturers is another indicator of rising demand. In Kenya, ACTS conducted a mapping exercise in early 2023 and identified 36 active manufacturers across the market[13].

Raw mangoes being cut and prepared for drying, India
Source: Raheja Solar Food Processing

xvii. When dried, 5 kg of fresh mangoes yield 1 kg of dried produce
xviii. Everlyn Okath, Interview by Liya Bensy Thomas, May 14, 2024

Solar dried produce packed for market
Source: Fiona Makayoto, ACTS

MARKET CHALLENGES AND OPPORTUNITIES

MARKET CHALLENGES AND OPPORTUNITIES

While solar dryers have a promising future, there are still challenges around cost, accessibility, technical skills and limited market linkages for dried products, which hinder the uptake of this technology.

Affordability

Affordability plays a key role in the adoption and market penetration of solar dryers, particularly among small-scale farmers. Transitioning from traditional open sun drying is challenging, as it involves no direct costs. Without any exposure to the market advantages of high-quality solar dried products, many farmers are often reluctant to invest in solar dryers, viewing them as an unnecessary expense rather than a value-enhancing investment.

Table 2: Indicative prices of solar dryers available in the market. Source: Interviews with solar dryer manufacturers

TYPE	TOTAL CAPACITY	REGION	PRICE (USD)
Cabinet solar dryer	40-100 kg	Kenya, Uganda	$1,500 - $2,000
Tunnel solar dryer	25-35 kg	Kenya	$300[xix]
Greenhouse solar dryer	100-500 kg	India, Kenya	$2,000[xx] - $4,500
	1-2 tonnes	India, Kenya	More than $7,000
Hybrid greenhouse solar dryer	100 kg	Kenya	$1,500

The average commercial-scale solar dryer costs over USD 2,000, making it accessible mainly to business-oriented farmers (see Table 2). Many small-scale farmers depend on support from organisations and development projects to cover these costs. Those unable to afford large-capacity solar dryers often rely on using smaller cabinet or tunnel dryers to dry produce in multiple batches, which can be time and resource-intensive.

The limited capacity of smaller dryers, combined with high costs, is a primary factor slowing adoption. Small-scale farmers often prefer open sun drying, which allows them to dry all their products at once, rather than investing in a dryer that can only process a portion of their produce per batch.

High manufacturing cost

Solar dryer manufacturing costs are significantly influenced by the price of food-grade materials used in the dryer such as drying trays made of stainless steel, or galvanised iron used in the metallic framework. These high-quality materials are expensive and often sold only in bulk, driving up upfront costs for manufacturers. Furthermore, materials such as galvanised iron, stainless steel, polycarbonate sheets, turbo ventilators, and blower fans are not readily available in the local markets in East Africa, and are often imported from countries like China, further increasing manufacturing costs.

Smaller dryers (10-100 kg) are more expensive to manufacture per unit of produce due to **material inefficiencies**. Even the smallest dryers require a minimum quantity of raw materials, meaning fixed costs do not scale down proportionately with the size of the dryer. As a result, the cost per unit of drying capacity is higher for smaller dryers, making them less economical to manufacture.

Bulk manufacturing potential

Manufacturing solar dryers in bulk could lower costs through economies of scale, but **current market demand does not support large-scale manufacturing.** This limited demand keeps high-quality solar dryers out of reach for many users, and instead allows cheaper but substandard solar dryers to dominate the market. These **low-quality dryers** are often made from materials that rust within months, and often feature ineffective designs that fail to dry produce properly. For instance, in Kenya, many inexpensive greenhouse solar dryers are not designed for drying but for growing crops. Local manufacturers make minor modifications to the greenhouse design and market these structures as greenhouse solar dryers[xxi]. Similarly, in Uganda, locally manufactured dryers are often produced without proper understanding of their functional and design requirements, leading to ineffective drying that fails to regulate moisture levels properly.

Given the **lack of awareness among farmers and small-scale agro-processors about the proper specifications and functionality of solar dryers**, they are often vulnerable to sales agents who promote poorly designed models for a lower price. These substandard structures fail to dry produce effectively, affecting quality and safety by exacerbating fungus and mould growth in dried products. This can lead to a loss of trust in solar drying technologies among users.

xix. This is the estimated price of a tunnel solar design that is not yet available in the market. It is designed with the goal of being more affordable
xx. Greenhouse dryer with a size of 3m×6m×2m and only 6 drying tables.
xxi. Florence Kiburi, Interview by Liya Bensy Thomas, May 8, 2024

The **significant price gap between locally made solar dryers and high-quality, durable models** intensifies the problem. Without greater awareness and education about the benefits and proper use of solar dryers, it remains challenging to overcome the dominance of the informal market and encourage widespread adoption of reliable solar drying solutions.

Market linkages

In Kenya, Uganda and Tanzania, the uptake of solar dryers is significantly hindered by farmers' limited market access for dried products. Many individual farmers and farmer cooperatives often struggle to reach the domestic market due to the poor quality of their dried products and limited customer base. While international markets have substantial demand for high-quality dried produce, they require production at a scale that few smallholder farmers or cooperatives can achieve. This capacity limitation prevents many from tapping into lucrative export opportunities.

Strict quality regulations for export markets demand high standards for both produce and packaging to avoid moisture formation. These regulations mandate the use of airtight, food-grade packaging, which are often challenging and costly for farmers to obtain. Without appropriate packaging, dried produce may become too dry, contaminated with high levels of microorganisms, and ultimately inedible. This is particularly important for products with high-sugar content, such as fruits, which require proper packaging to avoid moisture exchange with ambient air to prevent mould growth. Additionally, the thickness of the packaging also plays a significant role in moisture control, affecting the final cost of the product. For example, in Niger, farmers use hermetic bags to store dried jujube fruit, preventing moisture formation and insect infestation[14].

Such measures are crucial in humid environments where dried produce can reabsorb moisture and attract pests.

However, without guaranteed markets for their dried products, farmers are reluctant to invest in setting up drying units or purchasing necessary packaging materials due to the financial risk involved.

Financial support

The high cost of solar dryers is a major concern for many farmers, especially due to the lack of support from financial institutions. These institutions are often unfamiliar with post-harvest technologies and therefore **hesitant to provide loans or credit facilities** for solar dryer investments.

In Kenya, where the average monthly per capita farm income is approximately 2,000 KES[15] (USD 16), the price of a cabinet dryer—around 1,500 KES (USD 12)—constitutes 75% of a typical farmer's monthly earnings, making it unaffordable for most.

One potential solution to this initial cost barrier is the **"drying-as-a-service"** business model, which could make the technology more accessible to small-scale farmers and cooperatives by eliminating the need for upfront investment. However, in regions like Kenya, Uganda, and even India, drying is traditionally seen as a cost-free activity. For instance, the Kenyan Industrial Research and Development Institute (KIRDI) piloted a drying-as-a-service model in Kisumu County, charging 20 KES (USD 0.15) per kilogram of produce dried. This failed pilot highlighted the reluctance of people to pay for transportation and a service they can do for free. To encourage farmers to pay for drying services, there must be a clear benefit, such as linking farmers with buyers to secure a market for their dried products. See Case Study Two for an example of a successful drying-as-a-service model.

Technical skill gaps in fabrication and drying

A major barrier in the East African solar dryer market is the shortage of trained, skilled manufacturers capable of designing and manufacturing high quality dryers. Effective solar dryers rely on precise design elements, such as proper airflow, fan size, dryer size, number of trays, drying rates, and loading capacity to produce optimal drying conditions. Each of these factors require precise calculations and technical expertise. **The lack of skilled professionals** has led to many poorly designed dryers being sold in the market, produced with low quality materials, that fail to perform efficiently, deterring farmers from investing in this technology[xxii].

Limited awareness and knowledge among end users

Selecting the appropriate drying method for each type of produce is essential to maintain the product's nutrition and health benefits. For example, drying citrus fruits at temperatures above 60°C can significantly reduce their vitamin C content. In contrast, using mix-mode solar dryers, such as tunnel dryers, improves air circulation and maintains lower temperatures, helping preserve vitamin C in fruits like plums and gooseberries[16]. Key factors such as **drying method and temperature of drying**, as well as exposure to external air, can impact the colour, texture and nutrient levels of dried food products. Ensuring that food products are dried using the most suitable methods and conditions is crucial for preserving their nutritional value and overall quality. Without this knowledge, farmers often produce lower-quality dried goods, affecting their products' marketability.

xxii. Florence Kiburi, Interview by Liya Bensy Thomas, May 8, 2024

QUALITY ASSURANCE

The lack of standardisation in solar dryer technology has led to a market filled with competitive manufacturers offering cheaper, often inferior quality dryers. There is a pressing need for further research and development (R&D), and rigorous testing to develop standardised, efficient and affordable designs that guarantee durability and effectiveness.

Standards should provide guidelines on essential features, such as air circulation inlets and outlets, while allowing engineers' flexibility in design details. This approach would enable the development of optimally designed dryers suitable for various products without being overly restrictive, ensuring solar drying technology is both efficient and effective.

In the absence of a government-issued standard, manufacturers can get their solar dryers tested by VeraSol through a Rapid Product Assessment, which verifies the quality and performance of the dryers.

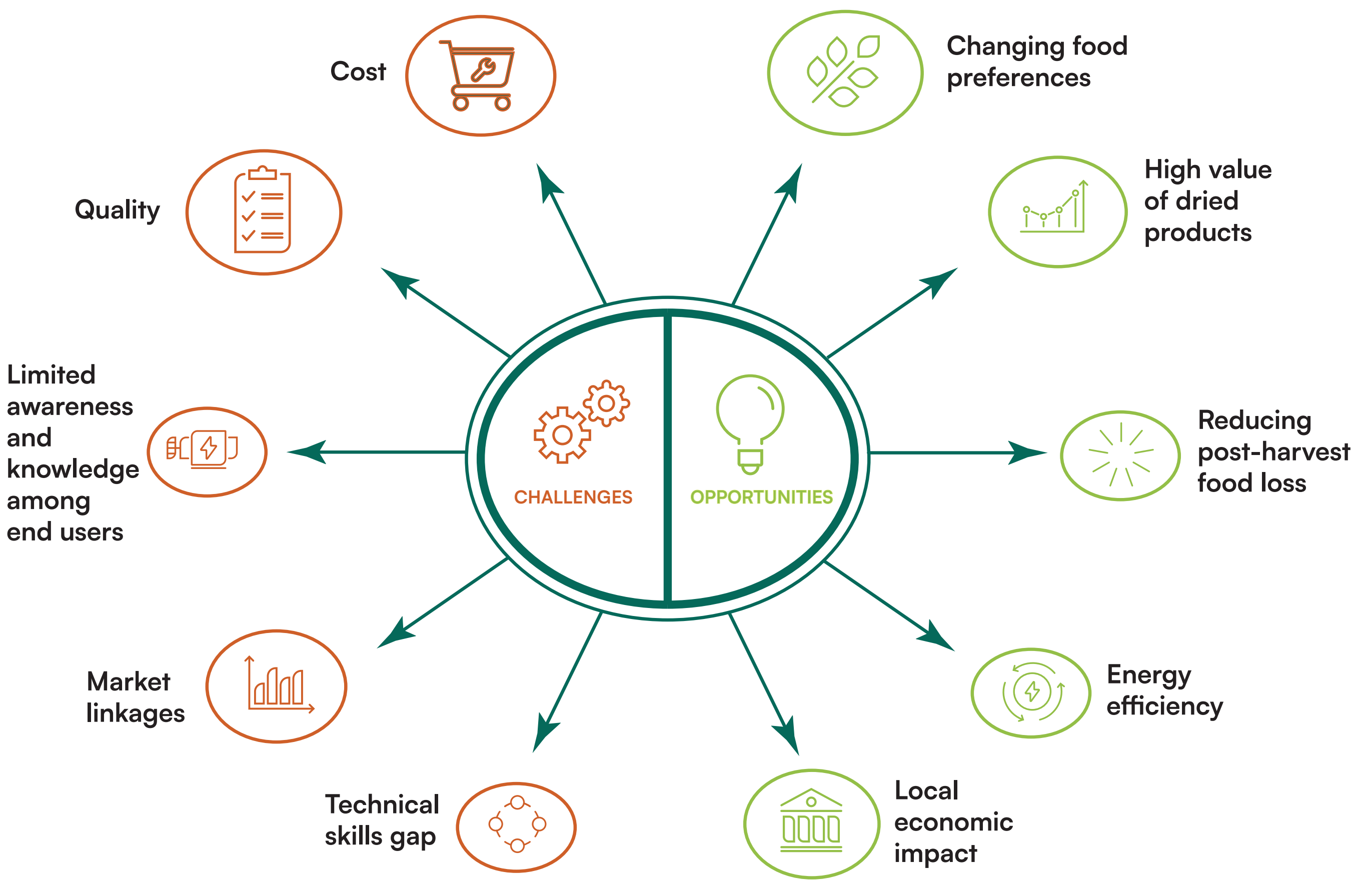
Efforts towards standardisation

Countries like Kenya are making significant strides in developing standards for solar dryers, while countries like Tanzania, Uganda, and India still lack specific regulations.

In **Kenya**, the Kenyan Bureau of Standards (KEBS) is drafting a standard to specify materials and specifications for solar dryers to qualify for the S-mark (Standardisation mark) for quality. This standard will set guidelines without limiting technological innovation. In the absence of a specific standard in Kenya, manufacturers and innovators often rely on parameters from standards for other light steel structures. Once the solar dryer standard is published, all solar dryers sold in Kenya will be required to display the S-mark stamp.

Although the standard for solar dryers is still under development, any solar dried produce intended for the market must meet existing export or domestic market regulations. In Kenya, dried fruits and vegetables must comply to national food standards[xxiii] to prevent contamination and mould issues, which are prevalent in open dried food products. Similarly, agro-processors supplying dried produce to the export market must adhere to packaging standards.

Figure 7: Market challenges and opportunities



xxiii. KS2786/2018 standards for dried fruits and KS435/2018 for dried vegetables.

CASE STUDY ONE

Hybrid greenhouse solar dryer installed by BioAfriq in Kenya
Source: BioAfriq

Innovations in solar drying technology in Kenya

BioAfriq's business model in Kenya centres on its innovative hybrid solar dryer design, which combines solar power with biomass energy derived from agricultural waste like maize cobs and dried mango seeds. This design ensures continuous drying even during rainy or low-sunlight periods by using clean-burning biomass fuels (briquettes). This approach addresses one of the major limitations of conventional solar dryers.

The dryers are designed to dry various types of products, each requiring different drying temperatures, such as 50°C for mangoes, 60°C for tubers, and 35°C for coffee. Digital temperature controls allow precise drying for diverse produce types, especially suited for commercial drying. Built with UV-treated polythene paper and galvanized steel components, the dryers are durable and resistant to environmental damage, and they come with a one-year warranty. With regular maintenance, the materials can last up to five years. Larger hybrid greenhouse solar dryers, with dimensions of 4 m x 8 m x 2m which can accommodate 9 dehydration tables, can cost over USD $4,000.

To address affordability challenges with hybrid solar dryers, BioAfriq offers portable, smaller semi-hybrid systems, measuring 1m x 0.5 m x 1m, priced at approximately USD $240. The company provides upgradable solar dryers, allowing users to add the hybrid system when financially feasible.

BioAfriq Energy sells approximately 150 units annually through donor-funded projects. To improve access of solar dryers, BioAfriq is partnering with the government to pilot a "drying-as-a-service" model in Makueni county. This service, offered at an affordable rate of USD $0.16 to USD $0.40 per kg, allows farmers to dry their produce and connect with buyers for their dried goods. BioAfriq has already partnered up with Taliana Foods Limited, which will purchase dried tubers from interested farmers to produce gluten-free flours.

CASE STUDY TWO

DIY tunnel solar dryers designed by Raheja Solar Food Processing in India
Source: Raheja Solar Food Processing

Buy-back Business Model for Dried Products in India

Raheja Solar Food Processing is a social enterprise based in Madhya Pradesh, India, dedicated to reducing post-harvest losses through value addition and market linkages.

Small scale farmers in India are often exploited by brokers due to their vulnerability and limited access to proper storage facilities. Farmers spend around INR 8 (USD $0.096) to grow 1 kg of tomatoes, yet brokers purchase them for less than INR 5 (USD $0.060) per kg. B-grade quality products, which are often rejected by the traders due to size or colour imperfections, are sold in the local market for a much lower price, sometimes as low as INR 2 per kg (USD $0.024).

Raheja's model offers farmers an alternative to exploitative supply chains by providing direct access to solar dryers, either sold directly to farmers or through donor-funded projects, and by offering a buy-back assurance for dried products. One popular and affordable solar dryer sold by Raheja is the foldable, portable, do-it-yourself (DIY) model (see Figure 8), capable of drying 20 to 100 kg of produce, reaching a maximum temperature of 60°C (± 10°C). These 40-foot-long solar dryers can be folded into a five-foot box, making them easy and convenient to install in remote locations. The 20kg capacity dryers cost around USD $285 and are designed for simple assembly by the farmer.

As an agro-processor, Raheja has set up five collection centres across India, located in Madhya Pradesh, Andhra Pradesh, Maharashtra, Arunachal Pradesh and Uttar Pradesh. Farmers can bring their dried products to these centres where they are checked and sorted by colour and size, ensuring farmers receive a fair price based on quality.

Figure 8: Raheja Solar Food Processing's business model in India
Source: Raheja Solar Food Processing

This buy-back business model gives farmers access to a market that would otherwise be difficult to reach.

Raheja adds value to the dried products by transforming them into items such as muesli with dried fruits, mango bars, soups, or tomato-infused oils. These products are then sold under white-label branding in both domestic and export markets. This model not only reduces post-harvest loss but also increases farmers' incomes by up to 50% by providing profitable opportunities for B-grade produce.

Training on drying mangoes in a greenhouse solar dryer
Source: Fiona Makayoto, ACTS

FUTURE OUTLOOK

FUTURE OUTLOOK

The market for solar dryers is expected to grow in the coming years, driven by rising demand for dried products and changing consumer preferences.

High nutritional value and potential health benefits of solar dried fruits and vegetables have caught the attention of increasingly health-conscious middle and upper middle-class populations. Unlike conventional open sun drying methods, **solar drying preserves higher levels of minerals and essential nutrients.** For example, solar-dried bitter gourd and capsicum retain higher levels of antioxidants, anti-inflammatory properties (polyphenols and flavonoids), and vitamins A and C compared to open air sun dried or hot air-dried samples[17]. Similarly, solar-dried tomatoes maintain more vitamin C and E content, which are otherwise significantly lost in prolonged open sun drying.

In recent years, **demand for healthier alternatives**, such as banana flour (made with dried bananas) over rice or maize flour, has increased slightly among the health-conscious upper middle class, with some **willing to pay a premium for the healthier option** (up to 30% more)[xxiv]. However, there is a low demand for dried products in the domestic market, especially in East Africa, where there is a cultural preference for fresh fruits and vegetables.

The global dried fruits market is expanding, driven by changing market dynamics linked to consumer demands. Dried products have a higher price per unit in local and international markets compared with fresh foods especially for fruits like mangoes. These markets offer an opportunity for farmers, especially in LMICs, to increase the value of their agricultural produce.

Consumers increasingly view dried products, especially fruits, as healthy, convenient alternatives to processed snacks. While most market research has focussed on European consumers, **there is notable growing demand in Southeast Asia**, where changing tastes and preferences signal new opportunities for dried products. Between 2009 and 2014, dried fruit consumption per capita increased significantly in the Asia Pacific region. This growth was driven by rising demand for healthy and convenient alternatives to fresh fruits, fuelled by increased disposable incomes[18]. Understanding consumer preferences is essential to tap into this lucrative growing market, driven by shifting diets and lifestyles.

There are some critical actions that policy makers and programme implementers could take to empower farmers to seize these market opportunities effectively.

A critical component of expanding the market for solar-dried products is **raising awareness** among users about the functionality, performance, and technical aspects of solar dryers. Future efforts should focus on comprehensive training programmes that cover the construction, maintenance, and operation of solar dryers. By demonstrating their efficiency, cost-effectiveness, and long-term benefits, these programmes can encourage wider adoption among farmers and small-scale producers, leading to increased production capacity and higher quality products.

Awareness campaigns should be designed to provide detailed market insights, including current trends and consumer preferences. These programmes should offer **practical advice on how farmers can effectively enter and compete in the market**, including access to financing, marketing strategies, and case studies of successful solar drying operations. By equipping farmers with this knowledge, they can capitalise on the growing demand for dried products, enhancing their incomes and contributing to the sustainability of the agricultural sector. Highlighting the health and nutritional benefits of dried products to consumers and businesses can help drive broader market acceptance and demand.

Establishing strong market linkages is crucial to enhancing the adoption of solar dryers and encouraging farmers, farmer cooperatives and agro-processors to participate in the dried foods market. Farmers often hesitate to adopt solar drying technology because they face challenges in finding reliable markets for their dried produce. To address this, it is important to **facilitate direct connections between farmers and buyers**, use digital platforms to reach a broader customer base, and encourage the formation of cooperatives to reduce market risk and enhance access to larger markets. These strategies can help ensure steady demand and better prices for dried products. By addressing the current market access challenges, these linkages can help unlock the full potential of solar drying technology, benefiting both farmers and the broader agricultural sector.

xxiv. Samuel Njugunas. Interview by Liya Bensy Thomas, May 13, 2024

FURTHER READING

Trends in Solar Dryers’ Uptake and Dried Food Markets Development in Kenya - A market analysis conducted by African Centre for Technology Studies in 2023, highlighting the manufacturing cost of different types and sizes of solar dryers and evaluating the target market’s willingness to pay for the solar dryers.

Gaps and Demand for Skill Development in Solar Dryer Fabrication - A policy brief outlining the need for training and technical skill development of manufacturers in Kenya, aimed at improving the quality of solar dryers available in the market.

A Knowledge and Business Resource Hub - Developed by African Centre for Technology Studies, this hub provides information on solar dryer manufacturers and dried food processors in Kenya.

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Lemon drying in a solar greenhouse dryer
Source: Raheja Solar Food Processing

CONTACT US

efficiencyforaccess.org

info@efficiencyforaccess.org

@EforA_Coalition

@Efficiency for Access

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