

LEAVE NO ONE BEHIND

BRIDGING THE ENERGY ACCESS GAP WITH
INNOVATIVE OFF-GRID SOLAR SOLUTIONS



SEPTEMBER 2024

Efficiency for Access Coalition

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ACKNOWLEDGMENTS

The report was authored by Martha Wakoli, Nyamolo Abagi, Kiplabat Tarus, and Shalom Mulinge of CLASP, in partnership with Harry Masters of Advancing Green Limited.

We are grateful to all the industry experts and stakeholders for their invaluable contributions to the learnings and insights shared in this report. The report was made possible through their comprehensive and thoughtful feedback and data. The authors are thankful to the following contributors and reviewers for their guidance and feedback throughout the project:

- Acumen: Chris Emmott
- Catalyst Energy Advisors: Maria Knodt and Ian Muir
- CLASP: Marina Baur, Jenny Corry Smith, Christine Egan, Yasemin Erboy Ruff, Sam Grant, Marion Kudla, Elisa Lai, Agnes Oloo, Aoibheann O’Sullivan, Ari Reeves, Corinne Schneider, and Sarah Wessler
- CrossBoundary: Tombo Banda
- Energy Saving Trust: Chris Beland, Leo Blyth, Emilie Carmichael, Charlotte Heffer, and Jakub Vrba
- ESMAP: Charlie Miller
- GEAPP: Makena Ireri
- GOGLA: Oliver Reynolds
- SunCulture: Hack Steinbald

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Front cover image: Futurepump customer in Kisumu, Kenya. Photo Credit: Futurepump

Efficiency for Access (EforA) is a global coalition dedicated to advancing highefficiency appliances to enhance clean energy access for the world’s most impoverished communities. Current EforA Coalition members have programs and initiatives spanning 62 countries and 34 key technologies. The coalition is cochaired by UK aid and the IKEA Foundation and funded by UK aid from the UK government, via the Transforming Energy Access platform. This material has been funded by UK aid from the UK government; however, the views expressed do not necessarily reflect the UK government’s official policies.



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DEFINITIONS

Term	Description
Solar Energy Kits	<p>These include solar lanterns, multi-light kits and solar home systems (SHS), and pico solar products under 10 Watt-peak (Wp).</p> <p>Solar home systems (SHS) have a solar panel rated between 11 Wp and 350 Wp and provide multiple electricity functions, such as lighting and powering appliances including TVs and fans. SHS are offered plug-and-play (PnP) or based on open-market components.</p>
Off-Grid Solar Appliances	<p>These include energy-efficient solar-powered appliances and equipment. They include both household and small business appliances and productive use of energy equipment and machinery. This report focuses on fans, solar water pumps, refrigerators, and grain mills.</p>
Productive Use of Energy (PUE) appliances	<p>These appliances cover a broad spectrum of energy-enabled products that improve livelihoods when used by customers to generate additional or new sources of income.</p>
Off-Grid Populations	<p>Communities that are not connected to national grids. These also include communities that are near to but still not connected to national grids.</p>
Weak-Grid Populations	<p>Households and communities that are connected to unreliable and poor-quality grid electricity. Unreliable grid electricity can cause frequent and/or lengthy power outages and power spikes that can damage electrical appliances.</p>
Addressable Market	<p>The share of the potential market that completely lacks access to electricity (i.e., the off-grid population) and can be served by existing off-grid solar (OGS) models. It includes all people who can be served by current business models and prices, assuming no affordability constraints. This represents the total number of key off-grid solar appliances needed to meet the needs of the global off-grid population, assuming that it will cost the same for companies to reach all households. This is different from previous editions of this report that also included weak-grid populations.</p>
Serviceable Market	<p>The share of the off-grid addressable market that can afford to purchase off-grid solar appliances by paying for them in installments over a period of one to three years. In previous editions of this report, this was referred to as an obtainable market.</p>

DEFINITIONS

Pay-as-you-go (PAYGo)

PAYGo business models allow users to pay their products via technology-enabled, embedded consumer financing. A PAYGo company typically offers a solar product for which a customer makes a down payment, followed by regular payments for a term ranging from six months to eight years, including interest above the retail price of the appliance. Payments are usually made via mobile money or alternative methods including scratch cards, mobile airtime, and cash.

Energy as a Service Model

A business model whereby a service provider (either traditional energy service providers or new ones, such as information and communications technology [ICT] companies) offers various energy-related services rather than supplying only electricity (i.e., kilowatt-hours [kWh]).

ACRONYMS & ABBREVIATIONS

AC	Alternating current
ACES	Africa Centre of Excellence for Sustainable Cooling and Cold-Chain Systems
AFDB	African Development Bank
AI	Artificial intelligence
ASCENT	Accelerating Sustainable & Clean Energy Access
B2B2C	Business-to-business-to-customer
B2C	Business-to-customer
BII	British International Investment
BLDC	Brushless direct current
CAGR	Compound annual growth rate
CCF	Concessional consumer financing
CO₂	Carbon dioxide
DART	Demand Aggregation for Renewable Technology
DC	Direct current
DFI	Development finance institution
DRE	Distributed renewable energy
DRC	Democratic Republic of Congo
EI	Energy Efficiency Index
EforA	Efficiency for Access Coalition
E-mobility	Electric mobility
E-waste	Electronic waste

ACRONYMS & ABBREVIATIONS

EnDev	Energising Development Programme
EPC	Electric pressure cooker
ESMAP	World Bank Energy Sector Management Assistance Program
EU-AIF	European Union Africa Infrastructure Trust Fund
EUR	Euro
FOREX	Foreign exchange
FSP	Financial service provider
GBP	Great Britain Pound
GDC	Global Distributors Collective
GEAPP	Global Energy Alliance for People and Planet
GGF	Green Genset Facility
GOGLA	Global Off-Grid Lighting Association
HH	Household
HP	Horsepower
ICT	Information and communications technologies
IDA	International Development Association (World Bank)
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IFC	International Finance Corporation
INR	Indian rupee
IoT	Internet of Things

ACRONYMS & ABBREVIATIONS

IRENA	The International Renewable Energy Agency
IRR	Internal rate of return
KES	Kenyan shilling
kW	Kilowatt
KWFT	Kenya Women Finance Trust
kWh	Kilowatt hour
LED	Light-emitting diode
LEIA	Low-Energy Inclusive Appliances
Li-ion	Lithium-ion
LMD	Last-mile distributor
MECS	Modern Energy Cooking Services
MEPS	Minimum energy performance standards
MFI	Microfinance institution
MFT	Modern farming technologies
MOU	Memorandum of understanding
MSME	Micro, small, & medium enterprises
MT	Metric tonnes
MTF	Multi-Tier Framework
MTR	Market Trends Report
NCAP	National cooling action plan
NEP	Nigeria Electrification Project

ACRONYMS & ABBREVIATIONS

OEM	Original equipment manufacturer
OGS	Off-grid solar
PAYGo	Pay-as-you-go
PCM	Phase change materials
PnP	Plug and play
PREO	Powering Renewable Energy Opportunities
PUE	Productive use of energy
PURE	Productive use of renewable energy
PV	Photovoltaic
RBF	Results-based financing
RWF	Rwandan franc
R&D	Research & development
SDD	Solar direct drive
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SHS	Solar home system
SOGAM	State of the Off-Grid Appliance Market
SPV	Special purpose vehicle
SSA	Sub-Saharan Africa
SWP	Solar water pump
TEA	Transforming Energy Access

ACRONYMS & ABBREVIATIONS

UNEP	United Nations Environment Programme
UPI	Unified Payments Interface
USAID	United States Agency for International Development
USD	United States dollar
U4E	United for Efficiency
VAT	Value-added tax
VIP	Vacuum insulated panel
WBG	World Bank Group
WICR	Walk-in cold room
WHO	World Health Organization
Wp	Watt peak
ZE-gen	Zero emissions generator

EXECUTIVE SUMMARY

Off-grid solar appliances can dramatically improve the lives of the world's poorest people. Today, however, they serve fewer than 2% of those who need them. The appliance sector must act rapidly to avoid leaving people behind in the race to expand energy access.

KEY FINDINGS

- Approximately 159 million off-grid solar fans, water pumps, refrigerators, and grain mills are needed to serve people who lack access to the electric grid. Less than 2% of this demand is being met, leaving more than half a billion people without life-changing appliances.
- Closing the energy service gap in sub-Saharan Africa and South Asia requires exponential growth in the appliance sector. This can be achieved by deploying significantly more capital, strengthening cross-sectoral collaboration, and developing coherent policies and innovative business models.
- There is a significant market opportunity of \$58 billion USD for off-grid solar fans, water pumps, refrigerators, and grain mills.
- The off-grid appliance sector is characterized by a multitude of business models, reflecting a diverse range of technologies, end users, and operating environments. There is no one right business model; rather, chosen business models need to be managed appropriately.

Millions of people lack access to the power grid, particularly in low-income rural areas of Africa and South Asia. If the current slow pace of electrification continues, 660 million people—most of them in Africa—will remain without electricity in 2030.¹

Households and businesses without electricity are forced to rely on a mix of energy sources ranging from open fires to batteries and diesel generators, leading to challenges such as air pollution and high costs. Compounding these issues, the appliances powered by these sources are often low-quality, inefficient, and expensive. As a result, people in off-grid settings typically have a lower quality of life, worse health outcomes, higher energy costs, and fewer economic opportunities than their grid-connected peers.

High-quality, efficient off-grid solar appliances are a proven solution to these challenges. For example, solar-powered refrigerators can reduce drudgery by

minimizing trips to the market, improve nutrition and healthcare by preserving food and medicine, and create new business opportunities such as food and beverage sales.

Off-grid solar appliances also help rural communities adapt to the worsening impacts of climate change. For instance, fans help people stay cooler during heat waves, while pumps increase the productivity, yields, and incomes of smallholder farmers.

THE STATE OF THE MARKET

[Efficiency for Access](#), a global coalition promoting high-performing appliances to support sustainable development and reduce carbon emissions, has tracked developments in the off-grid solar appliance sector since 2016. This research has provided crucial data about a proven alternative to universal electricity access.

This report—the third in the State of the Off-Grid Appliance Market [series](#)—finds that while the sector

EXECUTIVE SUMMARY

has strong fundamentals, it must rapidly grow in scale and ambition to avoid leaving people behind.

This report focuses on four off-grid solar appliances—fans, water pumps, refrigerators, and grain mills—with significant potential to enhance resilience and stimulate sustainable economic development in rural agricultural communities in sub-Saharan Africa and South Asia. Our analysis estimates a global demand for 159 million of these appliances in 2024. However, estimates show that only a few million are currently in use, indicating that existing sales meet less than 2% of the total need.

This vast gap between current and potential sales translates into a significant business opportunity. Our modeling shows that if everyone who needed an off-grid solar appliance could purchase one, the market value would reach \$58 billion USD.

To capture this value while transforming people's

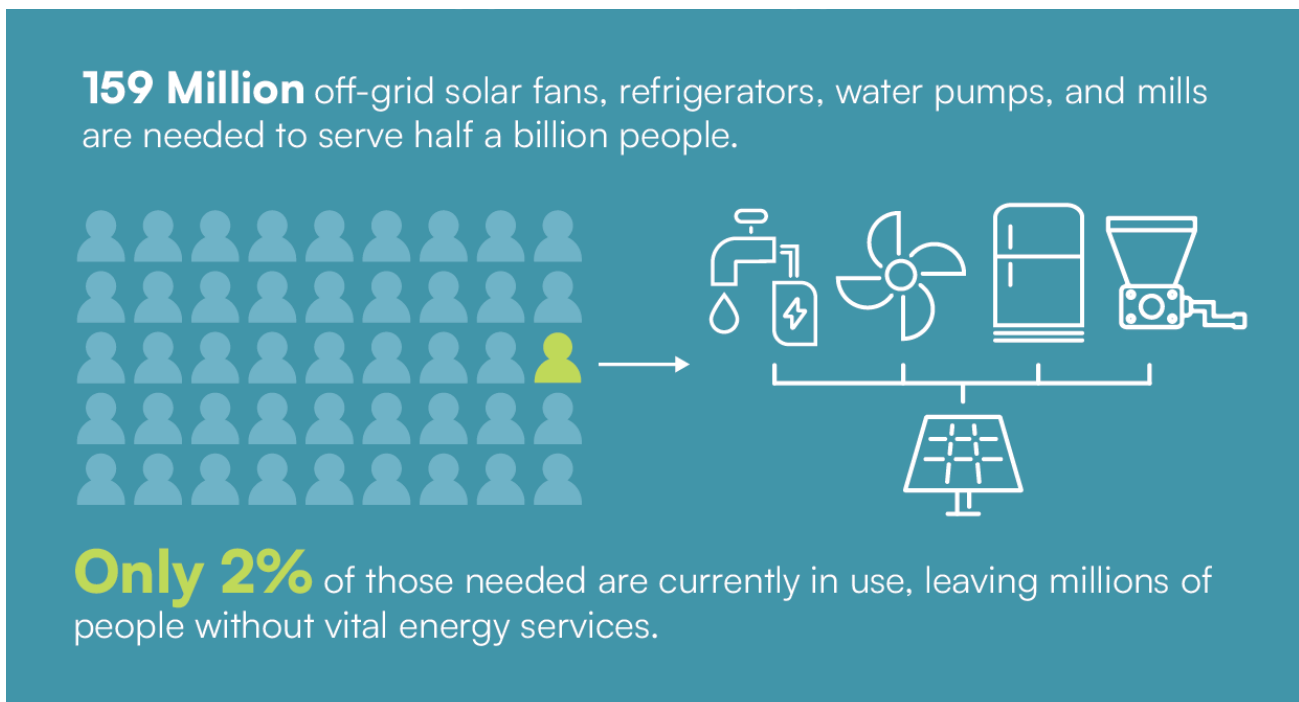
lives, the off-grid solar appliance sector must scale dramatically. Recent advances show that rapid growth is possible. Prior to 2018, cumulative sales of off-grid solar appliances totaled 1 million units;² in the five years after 2018, sales more than tripled.³ The number of products available has also increased as more manufacturers and distributors have entered⁴ the sector.⁵

This progress is even more noteworthy given the volatility of the past four years, with a pandemic, a global recession, and multiple geopolitical conflicts disrupting business activity.

IMPROVING AFFORDABILITY

Today, the sector must build upon these advances to extend its reach within the communities that need it most. This requires tackling the primary barrier to widespread access: consumer affordability.

Figure 1: Estimated number of solar off-grid fans, refrigerators, water pumps, and mills needed to serve over half a billion people versus those currently in use



EXECUTIVE SUMMARY

Consumer affordability is a complex issue influenced by multiple factors, including but not limited to:

Production cost: Off-grid solar appliances do not currently benefit from economies of scale that could lower the cost of production.

Customer awareness: Companies must invest heavily in building customer awareness since these appliances are new to many rural populations.

Distribution cost: Poor infrastructure (e.g., inadequate road networks) raises the cost of distributing appliances and limited digital connectivity complicates the use of PAYGo systems.

Quality assurance cost: Expenses related to independent testing and certification (to verify appliance performance and quality) are often passed on to consumers.

Difficulty obtaining credit: Young companies and low-income rural households face challenges in obtaining credit under favorable terms, limiting their ability to grow businesses and acquire new appliances.

Foreign exchange volatility: Many companies sell products in local currencies but service debt in foreign currencies, exposing them to significant risks from frequent and severe fluctuations in exchange rates. For instance, the Nigerian naira lost over 50% of its value against the US dollar within seven months between May 2023 and January 2024.

Our analysis shows that only 21% of the population in need of off-grid solar appliances can afford them at current prices, even with installment payments. This highlights a significant affordability gap within the broader addressable market, indicating a small serviceable market that can obtain these products.

Figure 2: Examples of factors that impact appliance affordability



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Supply-side challenges further complicate affordability. Manufacturers and distributors find it difficult to lower retail prices because of the high cost of distributing to remote areas and the small order volumes that are typical in the sector. This combination of high distribution and production costs keeps prices high, further limiting the reach of these essential technologies.

GAME CHANGERS

Several game changers could significantly accelerate the adoption of off-grid solar appliances.

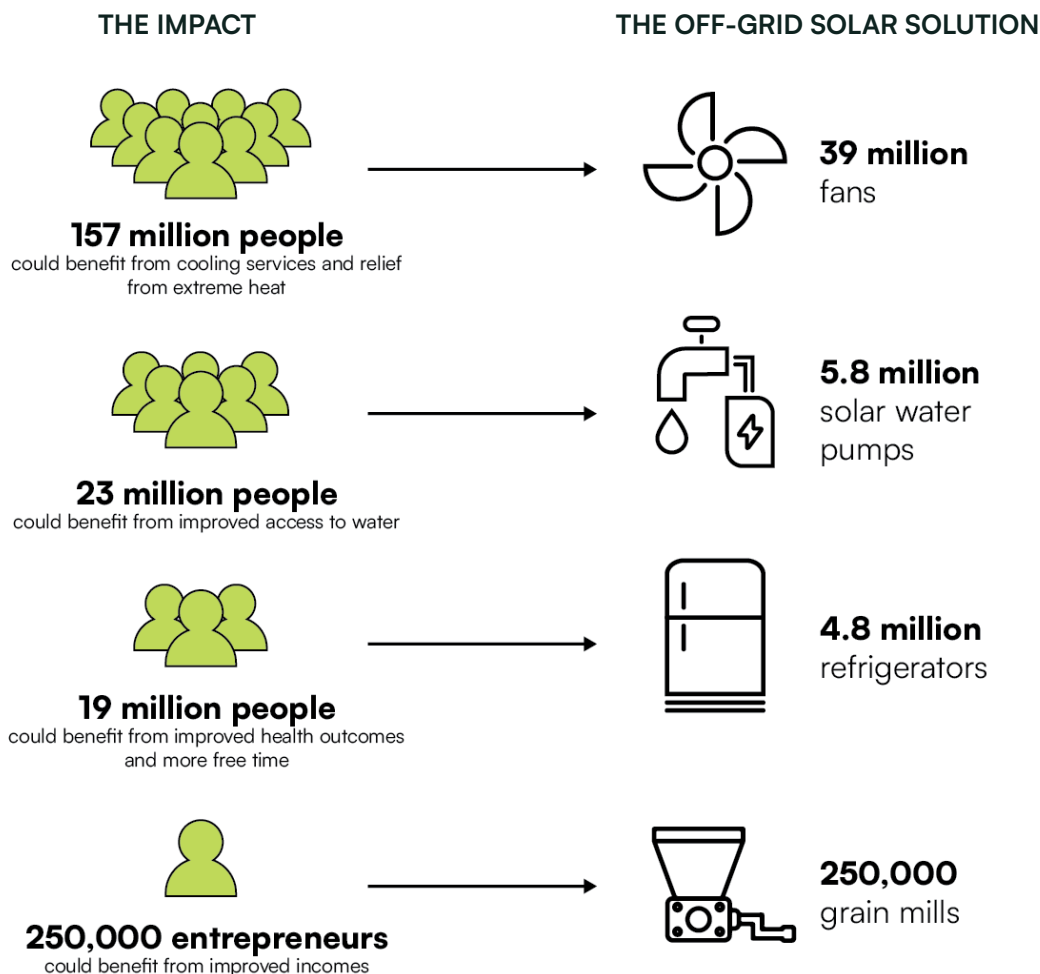
Innovations such as brushless DC motors enhance appliance efficiency, while the integration of artificial intelligence can optimize operations and user experience. Local manufacturing could also revolutionize the sector by reducing costs, shortening supply chains, and boosting local economies.

IMPACT AND ACTION

The policy and market ecosystem for solar off-grid appliances requires greater human and capital investment. If all market actors acted with speed and urgency to reach the serviceable market, they could benefit millions of people by 2030.

Figure 3: Potential impacts of off-grid solar appliances

HOW INNOVATIVE OFF-GRID SOLAR SOLUTIONS CAN BRIDGE THE GLOBAL ENERGY ACCESS GAP



EXECUTIVE SUMMARY

We recommend the following actions to realize this potential.

GOVERNMENTS:

- **Emphasize quality assurance and consumer protection**
 - Implement rigorous quality standards, promote right-to-repair policies, and ensure responsible end-of-life management for solar appliances.
 - Introduce tax and duty exemptions to make high-quality solar products more accessible, crowd out poor-quality products, and enhance overall market health and adoption.
- **Support an enabling environment**
 - Incentivize the local manufacture, assembly, and distribution of high-quality, affordable, and efficient off-grid solar appliances.
 - Launch comprehensive consumer awareness campaigns to educate the public on the benefits of using solar appliances, driving demand and adoption.
- **Develop integrated policies**
 - Establish cross-ministry task forces (e.g., bringing together ministries of energy, finance, and environment, as well as standards institutes) to integrate and harmonize policies and regulations, supporting solar appliance adoption and maximizing public funding impact.

INVESTORS, DEVELOPMENT PARTNERS, AND FINANCIERS:

- **Encourage market entry**
 - Significantly increase the deployment of capital (including concessional debt, equity, subsidies, and carbon finance) over the next ten years to foster new company formation in underserved markets and drive innovation.
- **Create public-private partnerships**
 - Develop programs combining public and private funding to expand distribution networks and scale operations.

• Integrate with climate finance

- Leverage carbon credits and other climate finance mechanisms to lower costs and make solar appliances more affordable.

• Provide innovation funding

- Provide financial support and resources to both local and foreign technology innovators to develop contextually relevant solar appliances.

TECHNOLOGY INNOVATORS:

• Prioritize local contextualization

- Design appliances that meet the specific needs of off-grid consumers, incorporating indigenous knowledge and user feedback.

• Enhance product durability and reliability

- Focus on long-term user satisfaction and low maintenance costs through improved product design.

VENTURE BUILDERS AND ENTREPRENEURS:

• Expand pay-as-you-go (PAYGo) models

- Promote diverse payment options and explore energy-as-a-service models to enhance affordability for low-income households.

• Leverage catalytic grants

- Use grants to innovate business models and build partnerships to reduce the risks of entering new markets.

• Explore disaggregation and specialization of business models

- Focus on specific market segments to enhance efficiency and increase market penetration.

ALL MARKET ACTORS:

• Prioritize user-centric data

- Collect information that directly benefits appliance users and minimizes intrusiveness. Offer consumers tangible incentives.

• Harmonize methodologies

- Establish standardized tracking systems for assessing progress and informing policy decisions.

EXECUTIVE SUMMARY

- **Facilitate data sharing**
 - Promote transparency and accountability, making data available to inform decision-making and policy development.



Solar-powered refrigerator user



Farmwarehouse customers using a solar-powered mill in Nigeria

INTRODUCTION

1.1 Background

Over the past five years, the world has faced severe climate, health, and economic shocks that have exacerbated extreme poverty and heightened inequality, particularly in parts of sub-Saharan Africa and South Asia. The World Health Organization reports that climate change is directly contributing to humanitarian emergencies including heatwaves, wildfires, floods, tropical storms, and hurricanes that are increasing in scale, frequency, and intensity.⁶ Recent examples include cyclones in Tanzania,⁷ floods in Kenya⁸ and Burundi,⁹ droughts in Zambia,¹⁰,¹¹ and extreme heat in Bangladesh, India, Thailand, and Vietnam.¹²

Concurrently, many of the countries experiencing climate disasters are still dealing with economic shocks worsened by the COVID-19 pandemic,¹³ which destabilized the world economy and triggered the largest global economic crisis in more than a century.¹⁴ The 2024 World Economic Outlook forecasts that global growth over the next five years will stay at 3.1%, the lowest rate in decades.¹⁵ Furthermore, the World Bank reports that between 2020 and 2022, the progress previously made in reducing global poverty was lost and that low-income countries have yet to recover from the economic downturn.¹⁶ In sub-Saharan Africa, where more than half of the world's extremely poor live, recovery has been especially slow and uneven.¹⁷

High-quality, efficient off-grid solar appliances can help people adapt to these challenging circumstances. By providing vital services such as cooling, access to information, and irrigation, they can strengthen climate resilience and contribute to meeting several UN Sustainable Development Goals.

ENERGY USE AND ECONOMIC DEVELOPMENT

In underserved regions of sub-Saharan Africa and South Asia, an estimated 685 million people¹⁸ remain

without electricity, while billions more are connected to unreliable grid networks. This lack of electrification and inability to power modern, efficient, grid-connected appliances undermines communities' capacity to cope with extreme temperatures, maintain food security, and improve livelihoods.

The strength of the relationship between energy use and economic development cannot be overstated. Countries that have successfully reduced poverty and improved living standards have typically increased their energy consumption significantly. Reliable electricity access catalyzes economic growth by allowing industries to thrive, enhancing educational opportunities, and improving healthcare services.

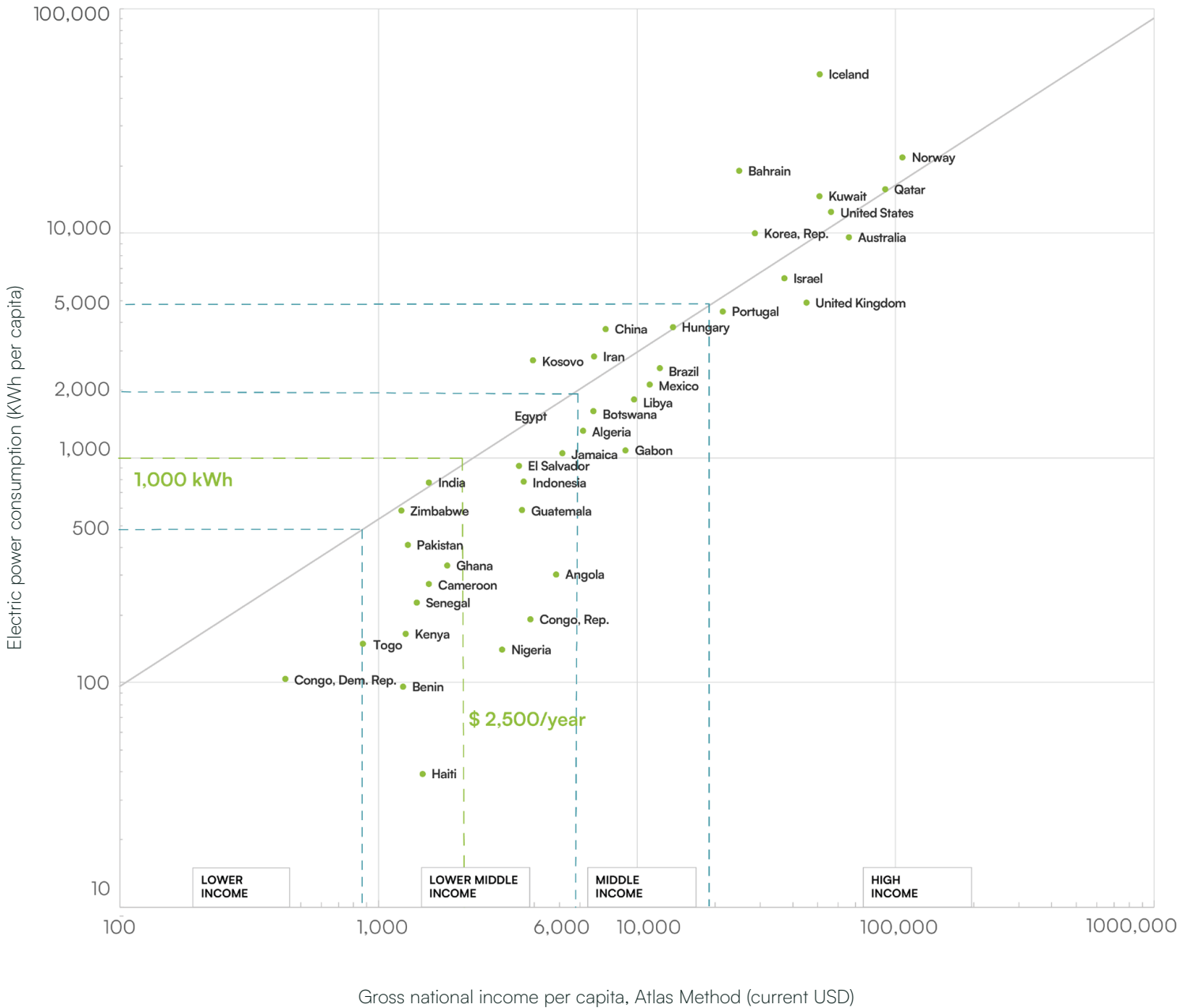
Countries with high energy consumption typically engage in intensive industrial activities and use advanced technologies, leading to a higher standard of living that includes the use of energy-intensive appliances and services. High-income countries, particularly those in the Global North, average about 6720 kWh in energy consumption per capita¹⁹—nearly 30 times more than low-income countries.²⁰ This disparity is illustrated in Figure 4, which shows that no high-income countries have low electricity consumption.

Conversely, many of the least-developed countries struggle with energy poverty, leaving over 3 billion people without reliable access to electricity. The average energy consumption in these regions is often less than 1000 kWh per capita per year, which is insufficient to support meaningful economic activities or enhance quality of life. This threshold correlates with an average income of about \$2,500 per year, which is typical for lower-middle-income countries.²¹

The narrowing window to address these global disparities by 2030, thereby truly leaving no one behind, calls for an accelerated pace of innovation and deployment in off-grid solar technology. Energy efficient solar appliances lay the groundwork to deliver on the vision of universal access. At the same time, they reduce overall system costs, lessen energy intensity, and deliver high-quality services.

Figure 4: Disparity in per capita electricity consumption between advanced and developing economies

INCOME VS ELECTRICITY CONSUMPTION



ABOUT THIS REPORT

This report is a flagship publication of the Low Energy Inclusive Appliances (LEIA)ⁱ program, the core initiative of Efficiency for Access and the world's leading research and innovation program for off- and weak-grid—appropriate appliances and technologies. Since its inception, LEIA's goal has been to double the efficiency and halve the cost of high-performing off- and weak-grid appliances, as defined in Figure 5.

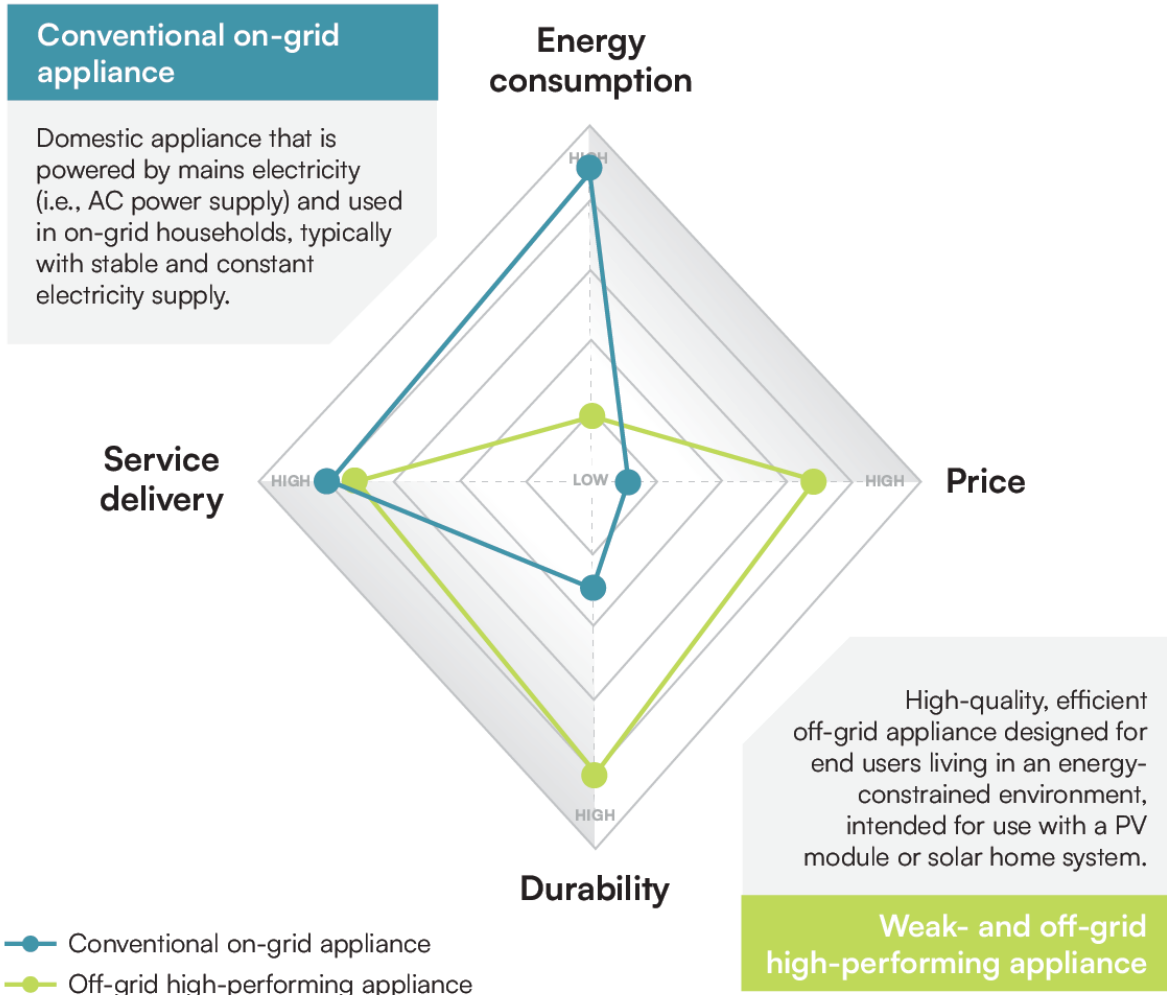
i LEIA is Efficiency for Access' flagship initiative. LEIA is funded by UK Aid, via the Transforming Energy Access (TEA) platform and the IKEA Foundation with contributions from Good Energies Foundation.



Farmer using solar irrigation in Ethiopia

Figure 5: Categorization of appliances²¹⁶

FEATURES OF APPLIANCE TYPES

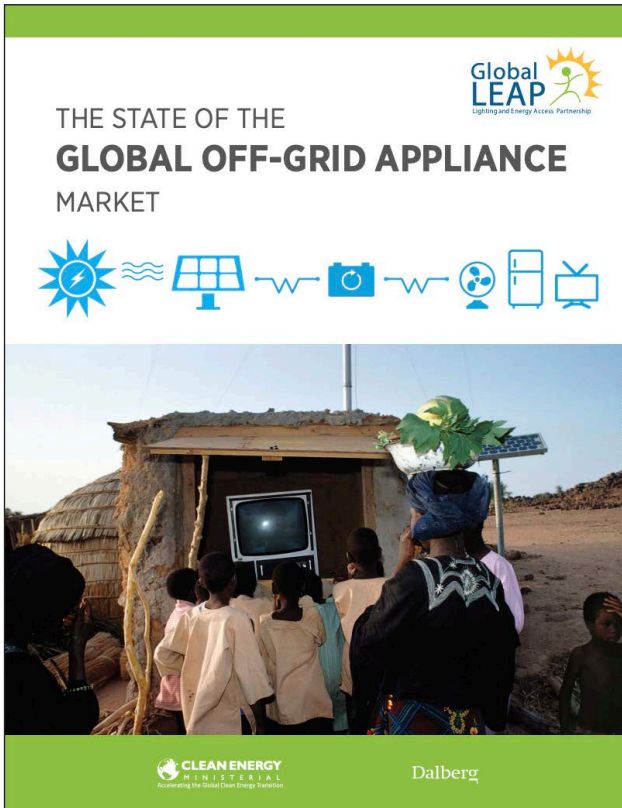


EVOLUTION OF THE STATE OF THE OFF-GRID APPLIANCE MARKET REPORTS

Progress towards LEIA’s ambitious goal has been tracked and reported in the [State of the Off-Grid Appliance Market \(SOGAM\)](#) series, with the first comprehensive assessment appearing in the 2017²² report. That document provided a snapshot of the global off-grid appliance market, marking the beginning of a systematic exploration of scale, market trends, and barriers across key appliance categories including televisions, refrigerators, and fans.

The 2019²³ iteration of the report expanded upon these findings by including solar water pumps and integrating richer data sources, such as Efficiency for Access Coalition research, GOGLA (Global Off-Grid Lighting Association) survey data, and insights from in-depth profiles for countries like Côte d’Ivoire, Ethiopia, India, Kenya, Myanmar, Nigeria, Sierra Leone, and Uganda. This second report detailed the diversity of challenges and opportunities within the sector and provided predictions on how rapidly these technologies could scale.

State of the Off-grid Appliances Market reports: 2017 (left) and 2019



This third iteration of the report builds on previous editions. By delving deeper into technology, price, sales, and regulatory trends, it aims to provide comprehensive insights into the sector’s dynamics and outline clear pathways for future growth.

This report centers on three leading appliance markets: India, Kenya, and Nigeria, extrapolating data from these countries to offer a global perspective. It includes discussions of the following:

- **Market assessment:** Estimates the global addressable and serviceable markets for key off-grid solar appliance categories—fans, water pumps, refrigerators, and grain mills—and highlights the factors that influence their sales.
- **Technological trends:** Explores advancements in technology that enhance the efficiency and functionality of off-grid appliances, impacting both market penetration and consumer adoption.

- **Business models:** Analyzes the different ways that off-grid appliances are designed, manufactured, and distributed in different markets.
- **Financial insights:** Discusses the variety of financing mechanisms available and their role in facilitating access to off-grid solar appliances, including consumer financing, subsidies, and innovative funding models.
- **Game changers:** Identifies potential breakthroughs and innovations such as local manufacturing capabilities, AI integration, and other technological advancements that could dramatically shift market dynamics.

Case Studies: Presents detailed case studies from India, Kenya, and Nigeria to illustrate successful strategies for scaling the sector and the practical application of new technologies in the off-grid solar appliance market.

By synthesizing findings from diverse appliance markets and assessing significant trends in technology, financing, and distribution value chains, this report not only contextualizes the current state of the off-grid solar appliance market but also sets the stage for future interventions. The recommendations offered aim to accelerate progress towards bridging the appliance access gap, emphasizing:

- the link between access to appliances and achievement of energy access and sustainable development goals
- the importance of quantifying appliance access gaps and the market opportunity of addressing them
- the need for all market actors to prioritize speed, scale of investment, and productive partnerships

LIMITATIONS

While this report draws insights from the best available data, this data is often sparse and self-

reported, especially for smaller markets. More granular data is required to more accurately represent the state of the market. Key limitations of the data gathered for this report include:

- **Scope and assumptions:** We developed detailed market sizing models for India, Kenya, and Nigeria and extrapolated those outputs to a global sample. These countries have relatively mature appliance markets with better-understood distribution models, more available retail prices, and frequently updated income distribution data. This extrapolation provides a reasonable approximation but does not entirely represent markets with more severe access deficits, which often have lower incomes, higher retail prices (due to infrastructure deficits), and fewer distributors selling off-grid appliances.
- **Specificity:** There is still a lack of clarity regarding the exact amount of financial investment going directly to off-grid appliances rather than the off-grid sector more broadly.



Solar-powered pump users in India
Photo Credit: Prashanth Vishwanathan

1.2. Why are off-grid solar appliances important?

Off-grid solar appliances offer an accessible, scalable solution for advancing sustainable development and climate resilience. They contribute to international climate goals across multiple tracks:

- **Sustainable development:** Efficient appliances enable households and businesses to develop new sources of income.²⁴
- **Climate adaptation and resilience:** Solar appliances enhance community resilience by providing sustainable, uninterrupted energy supply, critical for adapting to the impacts of climate change and economic shocks.²⁵ They enable households and businesses to maintain operational continuity during power outages and infrastructural challenges.
- **Emissions avoided:** Solar appliances can displace fossil fuel-powered pumps and mills and help countries transition to low-emission development pathways while meeting energy access goals.

In this report, we focus on the benefits of four key appliances: fans, refrigerators, solar water pumps, and grain mills. These appliances were selected for their significant potential to impact economies and society. They also represent different stages of technological and commercial maturity, providing

a more comprehensive overview of the market. By highlighting these technologies, this report underscores the transformative potential of solar appliances to address critical energy, health, and economic challenges.

COOLING

According to SEforALL's Chilling Prospects report series,²⁶ over 1 billion people across the 54 countries at highest risk from extreme heat, food loss, and damaged or destroyed vaccines and medicine remain at high risk from a lack of access to cooling. This includes 318 million people living in poor rural settings who likely lack access to the electric grid.

FANS

In many of the world's hottest regions, fans are essential for improving indoor air quality and reducing heat stress. Solar-powered fans offer a sustainable solution that can operate independent of grid electricity, providing relief during heatwaves and improving comfort in off-grid areas. This ability, in addition to low operational costs, makes solar-powered fans an accessible cooling option for the most vulnerable populations. By circulating air, fans also help mitigate health risks from airborne diseases and reduce the prevalence of insects like mosquitoes that are vectors for malaria.^{27, 28}



Family in Bangladesh using a fan for cooling

REFRIGERATORS

Solar-powered refrigerators transform how communities store food and medicine. In off-grid areas, refrigerators make perishables last longer, reducing waste and improving food security. For households and businesses, they provide the means to store and sell chilled products, which can significantly boost income.

This was demonstrated in a recent field test in Rwanda²⁹ that studied how five consumers used solar-powered refrigerators. The respondents used these appliances for household needs, but also to

store salable goods such as soft drinks, alcoholic drinks, meat, and fish. Four consumers reported a weekly income of approximately 80,000 RWF (\$60 USD) from these sales, while one reported earning more than double this amount.

Refrigerators also free up time, particularly for women and children who otherwise typically spend much of their day procuring and cooking fresh food. In healthcare settings, they are critical for storing vaccines and medicines, directly impacting community health outcomes.



Solar refrigerator in use in Uganda

IRRIGATION

Approximately 95% of farmland in sub-Saharan Africa and 60% in South Asia is rainfed, leaving most smallholder farmers to rely on unpredictable weather to water their crops.³⁰ Solar water pumps (SWP) enable reliable water access for irrigation, greatly enhancing agricultural productivity and food security. These pumps are particularly valuable in rural farming communities where electricity is unreliable or unavailable. By providing a consistent water supply, they allow farmers to cultivate larger areas and grow crops more efficiently, leading to increased yields and income. Solar water pumps also reduce dependency on diesel-powered irrigation systems, cutting down on greenhouse gas emissions and operational costs.

Field testing conducted by Efficiency for Access across India, Kenya, Rwanda, Senegal, and Tanzania over the last three years has substantiated these benefits.³¹ In Rwanda, 87% of the 15 farmers who acquired a SWP reported an increase in their monthly incomes, while 64% indicated hiring additional laborers and adding new crops.

SWPs have some limitations, however: They may not be well suited for arid regions and have reduced functionality during droughts.³²

MILLING

Grain milling is a traditionally labor-intensive process that can be automated with solar-powered mills. These appliances save time and reduce physical labor while increasing efficiency in food processing. By using them, rural communities can boost local food production and support small-scale agribusinesses.

Additionally, solar mills contribute to rural economic development by lowering energy costs. Cross Boundary's latest Innovation Insight³³ estimates that transitioning from diesel to electric grain mills in sub-Saharan Africa could generate \$2.5 billion USD in annual value by 2030 while saving over five million tons of carbon emissions each year.³⁴ Enhancing solar-powered agro-processing more broadly is particularly important because of its potential to eliminate polluting diesel fuel and create job opportunities in rural areas.



AgSol mill customer using a solar-powered milling machine
Photo Credit: Agsol

JOB CREATION AND LIVELIHOOD IMPROVEMENTS THROUGH OFF-GRID SOLAR APPLIANCES

Off-grid solar appliances can positively impact communities in rural sub-Saharan Africa and South Asia by providing essential services as well as fostering economic opportunities. These technologies catalyze job creation across various sectors, particularly agriculture, which is the largest employer in these regions, accounting for an estimated 50% to 85% of the labor force.³⁵

For example, solar-powered irrigation systems and

grain mills enhance agricultural productivity and efficiency, leading to the creation of new jobs in appliance installation, maintenance, and operation. Efficiency for Access research shows that these technologies can create over 115,000 jobs by 2030 in countries like India and Kenya, providing higher incomes and better job opportunities for rural communities.³⁶ Moreover, by enabling more reliable, efficient agricultural practices, these appliances help transition farm workers into less physically demanding roles, improving quality of life and boosting productivity.

APPLIANCE IMPACT

“

Nearly all off-grid products can contribute to some form of economic impact . . . Around one in five energy customers use their energy access to support or start a business and/or wider income-earning activity. Appliances are the most productively used product category.

— 60 Decibels, *Why Off-Grid Energy Matters*²¹⁷

”



Koolboks customer Doris Chuwa in Nigeria
Photo Credit: CLASP

BOOSTED INCOME WITH AFFORDABLE AND RELIABLE COOLING SOLUTIONS BY KOOLBOKS, NIGERIA

“Since I [bought a Koolboks fridge], I noticed the business has changed. When my customers come to me saying they have no power supply and ask how I have electricity, I tell them I am using Koolboks to chill my drinks. If you have this [fridge], your business will change.”

— Doris Chuwa,
Koolboks customer

1.3. How do off-grid solar appliances support the achievement of SDG 7?

Off-grid solar appliances are critical for achieving the UN's Sustainable Development Goal 7 (SDG 7), which promotes access to affordable, reliable, sustainable, and modern energy for all.

Between 2010 and 2022, 1.4 billion people gained access to electricity globally³⁷ because of initiatives aimed at expanding the power grid. These grid extension efforts have primarily focused on densely populated areas where infrastructure development is more cost-effective.

However, service levels vary widely even in grid-connected areas, with many regions experiencing frequent power outages. In areas with weak grids such as in Bangladesh, India, and Nigeria, residents use standalone and hybrid solar solutions to provide reliable backup power during outages. For instance, of the 190,000 solar fans sold in Bangladesh between 2017 and 2019 with support from Global LEAP's results-based financing mechanism, 28% were purchased by users already connected to the grid who intended to use them for this purpose.³⁸

Today, most people with no access to electricity live in rural areas. Rural electrification faces several critical challenges:

- **Low electricity consumption:** Many people in rural areas have low electricity usage due to a lack of appliances. This low consumption translates into minimal revenues for both traditional grid operators and mini-grid providers. For example, a 2024 study on rural electrification in India found that for a 300-person village, the financial benefits from electricity consumption over 20 years might not exceed the initial costs of electrification, leading to a 0% internal rate of return (IRR).³⁹
- **High upfront costs:** Extending traditional grid infrastructure to remote areas can be prohibitively expensive, with rural grid connections costing approximately \$2,000 USD per connection versus \$1,200 USD for urban connections.⁴⁰ Mini-grid installations also require significant capital, which can be difficult to recoup if the local population does not consume enough electricity to generate sufficient revenue.

- **Lack of incentives:** Without external support from governments or development partners, electrifying rural areas is often viewed as a loss-making venture. The financial frameworks in many energy-deficit countries do not offer sufficient incentives for private investment in rural electrification, resulting in a dependence on public funding and donor support.

Largely because of these challenges, if the current pace of grid extension continues, 660 million people, most of them in Africa, will remain without grid connectivity in 2030.⁴¹

Given the high cost of grid extension, decentralized solutions like standalone solar appliances, mini-grids, and hybrid systems are essential for closing the energy access gap. However, the success of universal electrification efforts hinges on ensuring that consumers have access to appliances that meet their needs and enable them to utilize their new energy supply. Off-grid appliances not only provide a financial rationale for developing mini-grids in rural areas but also offer essential energy services in the absence of mini-grids and regional power grids.

FRAMEWORKS FOR MEASURING ENERGY ACCESS

The growing recognition of off-grid solar appliances' role in enhancing electricity access highlights the need for a well-defined benchmark to understand "energy poverty" and set realistic targets for energy access initiatives. In an attempt to achieve this, the Energy Sector Management Assistance Program (ESMAP) developed the [Multi-Tier Framework \(MTF\)](#), which categorizes energy access into tiers based on capacity, duration, reliability, and quality.

While the MTF provides a helpful initial approach to solving this challenge, it has notable limitations. It assumes that households with electricity access possess the appliances needed to utilize it effectively, which is often not true, particularly in low-income and rural areas. In addition, the framework focuses largely on household energy, ignoring the essential needs of businesses, schools, and healthcare facilities that are crucial for economic and social well-being.

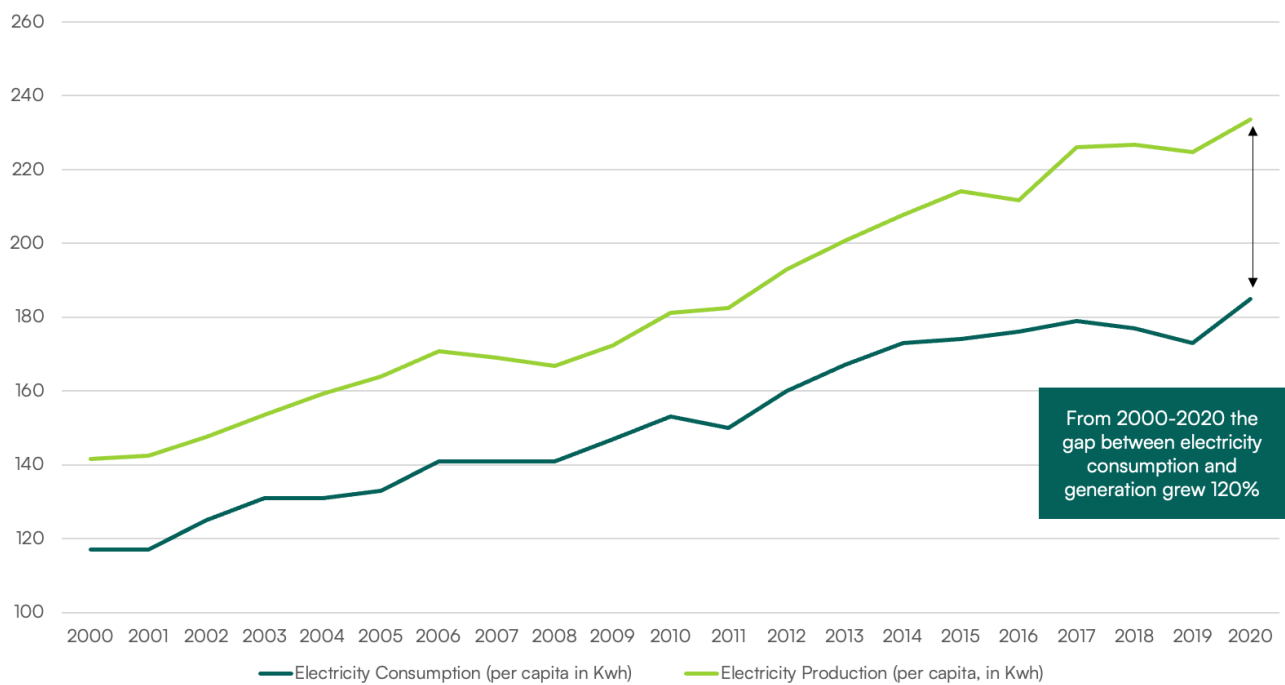
In Kenya, for example, although the percentage of the population connected to the grid increased from 15% to 76% between 2000 and 2022, the actual usage of electricity has not risen proportionally. This discrepancy suggests that simply increasing grid

connectivity does not equate to enhanced energy usage, as illustrated by the 120% gap between electricity consumption and generation in the nation between 2000 and 2020 (Figure 6).

To improve these measurement frameworks, it is crucial to establish a clear benchmark that includes a specific basket of appliances for higher MTF tiers. For instance, specifying that tier three or higher should include access to essential appliances such

as fans, refrigerators, and productive use equipment like grain mills provides a practical and tangible framework for assessing energy access. This detailed approach is crucial for effectively shaping policies and guiding investments towards achieving SDG 7. It also empowers households and communities to understand their expected level of energy access, improving their overall quality of life and supporting economic and social well-being within their communities.

Figure 6: Electricity generation vs. consumption in Kenya, based on IEA data²¹⁸



1.4. What game changers will drive the growth of the off-grid appliance market?

Some predictions from the first two reports in this series, though insightful, did not fully anticipate the scale of challenges and the pace of market evolution observed in the years since. Significant gaps and limitations in data during previous analyses, coupled with fast-changing market dynamics, have necessitated a re-evaluation of our assumptions and methodologies.

Drawing from the best available data and refined analytical techniques, this section outlines the game changers that could catalyze significant growth in this sector over the next decade.



ENHANCED INTEGRATION OF DECENTRALIZED SYSTEMS WITH THE NATIONAL GRID

Future efforts will focus on integrating solar appliances with grid infrastructure to enhance reliability and reduce dependency on fossil fuels. Hybrid solutions that combine solar appliances with grid extension efforts will provide a more reliable and resilient energy supply.

Supportive policies and incentives for integrating solar solutions with the grid will be essential for this transition. The World Bank's Accelerating Sustainable and Clean Energy Access Transformation (ASCENT) program exemplifies this approach. Launched at the end of 2023, ASCENT aims to accelerate access to electricity for 100 million people in Eastern and Southern Africa by leveraging a \$5 billion USD International Development Association (IDA)

envelope and mobilizing an additional \$10 billion USD from various partners. The program supports the integration of decentralized energy systems with national grids, promoting hybrid solutions to improve energy reliability and resilience. Additionally, ASCENT aligns with sectors such as digital, agriculture, health, and education to drive synergies in financing and impacts.



IMPROVED PERFORMANCE, QUALITY, AND EFFICIENCY OF KEY PRODUCT COMPONENTS, PARTICULARLY BRUSHLESS DC (BLDC) MOTORS

Brushless DC (BLDC) motors present significant opportunities to transform the agriculture sector in sub-Saharan Africa and South Asia by improving the performance, quality, and efficiency of solar-powered agricultural appliances. BLDC motors convert power into mechanical output more efficiently, making them particularly useful in applications like mills, irrigation systems, threshers, shellers, grinders, and other post-harvest processing equipment. For instance, Agsol's solar-powered MicroMill uses a custom BLDC motor that is over 2.5 times more efficient than conventional electric mills, allowing it to operate with smaller solar panels and batteries, thus lowering costs in off-grid areas.⁴²

In solar irrigation, BLDC motors significantly reduce the energy demand of solar pumps, which are the largest energy consumers in such systems. The use of these high-efficiency motors can decrease the size and cost of required solar panels, making solar irrigation more affordable and practical, despite the slightly higher initial cost of the motors.

In Pakistan, where over six million people endure sweltering summers without reliable energy, development programs are financing the installation of

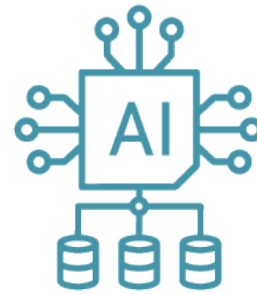
more than 350,000 solar home kits that include highly efficient fans equipped with BLDC motors. This initiative was encouraged by Efficiency for Access's performance test results, which led local manufacturers to upgrade their fan designs with BLDC motors. The proximity to major local motor and fan manufacturers, coupled with transformative investments and subsidies, has fostered significant improvements in fan design within the country. Consequently, pedestal and ceiling fans with BLDC motors have shown a substantial increase in efficiency, with some models improving by over 200%. Enhanced product quality has also enabled manufacturers to offer warranties of one to two years.⁴³



RIPPLE EFFECT OF E-MOBILITY

The increasing adoption of electric mobility (e-mobility) will significantly influence the growth of the off-grid solar appliance market. As e-mobility becomes more widespread, it will create new opportunities for innovation in the market.

- The growing need for energy storage to support electric vehicles will boost the availability of rechargeable batteries. This will facilitate greater use of second-life rechargeable batteries for stationary applications in off-grid solar systems.
- E-mobility will create new business opportunities for off-grid solar appliances. For instance, vehicle-based cooling storage, as well as service-based irrigation systems powered by e-bikes that transport solar pumps from farm to farm, will become more prevalent.
- E-mobility will create new opportunities for improving energy efficiency in off-grid solar appliances. For instance, the use of advanced battery management systems (BMS) will enable more efficient energy storage by reducing energy losses.



DEPLOYMENT OF ARTIFICIAL INTELLIGENCE (AI) AND BIG DATA

AI and big data are poised to significantly influence the growth of the off-grid solar appliance market in several key ways.

DEMAND FORECASTING AND RESPONSIVENESS

AI and predictive analytics help off-grid solar companies better understand and respond to customer demand. By analyzing data on energy consumption patterns, demographics, weather patterns, and market trends, AI models can identify optimal regions for expansion and target specific customer segments with tailored products and services. This data-driven approach enables companies to make more informed decisions and allocate resources more efficiently.

For example, Engie Energy Access utilized [Atlas AI's Aperture platform](#) to boost its monthly sales by 48% in a 2022 pilot program in Kenya. Recognizing the need to prioritize customer qualification and acquisition to expand its business, Engie leveraged the platform's robust data capabilities to strategically identify and monitor local communities in Kenya, pinpointing areas where it could concentrate growth efforts effectively.

FINANCING

AI and big data significantly enhance financing opportunities within the off-grid solar appliance market. AI-powered digital verification models streamline the process of connecting end users with financiers, ensuring authenticity and direct benefits from financial mechanisms like carbon credits.

A notable example is Nithio, operating in Kenya and

Nigeria, which utilizes AI and blended finance to provide a sustainable, risk-informed approach to financing off-grid solar solutions. Nithio's AI system assesses customer creditworthiness to tailor the type of capital offered, providing commercial capital for low-risk customers and grants or results-based financing for higher-risk groups, such as low-income families and residents of informal settlements.⁴⁴



PREVENTATIVE MAINTENANCE AND AFTER-SALES SERVICES

AI and Internet of Things (IoT) technologies support preventative maintenance and improve after-sales services for off-grid solar appliances. By continuously monitoring appliance performance and analyzing data on usage patterns and component health, AI models can predict potential issues and trigger preventative maintenance actions. This proactive approach reduces downtime, extends appliance lifespans, and improves customer satisfaction. Innovators like SunCulture and EcoZen are already integrating these features into their products.

CONSUMER AWARENESS AND EDUCATION

AI models integrated with off-grid solar appliances promote consumer awareness and education. For example, AI-powered virtual assistants can help smallholder farmers maximize the benefits of their solar appliances by providing interactive tutorials, troubleshooting guides, and real-time feedback on appliance performance.

INTELLIGENT LOAD MANAGEMENT

As the grid becomes more integrated and the demand for energy storage increases, AI algorithms can optimize the use of limited energy resources. AI can allocate power to different appliances and devices, optimizing energy distribution and minimizing waste. For instance, a cold storage facility using AI can reduce energy consumption by 15% by optimizing refrigeration settings and adjusting energy usage during peak hours. On a household level, AI can help off-grid users optimize energy consumption and usage of devices like smart home systems.

However, the cost-effectiveness of integrating AI must be carefully evaluated against the price of the appliance itself. While AI solutions can offer

substantial savings for larger or communal appliances, their cost might not justify their use for smaller household devices for price-sensitive user groups.

LOCAL MANUFACTURING AND ASSEMBLY

Local manufacturing and assembly of off-grid solar appliances can play a crucial role in reducing costs, creating jobs, and mitigating supply chain shocks. Countries like India and Nigeria have demonstrated the benefits of local production for specific appliances, including reduced reliance on imports and increased local capacity.

One key opportunity is technology transfer between Asia and Africa. Markets like Bangladesh, India, and Pakistan (see Case Study 2) have already established local assembly of off-grid fans and other appliances. These technologies and manufacturing processes can be adapted and transferred to African countries to kickstart local production.

Local assembly allows for customization of products to meet specific market needs. In Nigeria, the government's Economic Sustainability Plan 2020 includes a solar strategy that incorporates local assembly in three phases: proof-of-concept, scale-up with incentives, and maturity, with the maturity phase focused on sustaining assembly and expanding to manufacturing.⁴⁵ This approach allows for adaptation and optimization of products for the Nigerian market.

Local manufacturing can also create jobs and build technical skills. Governments can leverage this ability by developing targeted policies that incentivize investment in local production and create employment opportunities.⁴⁶ For instance, in Rwanda, a policy assuring off-take of locally assembled products at market prices has attracted foreign direct investment into a solar product and LED light assembly company.⁴⁷

Realizing the benefits of local manufacturing and assembly will require overcoming challenges including:

- a lack of quality standards for assembled products
- country macroeconomics that make it difficult to compete with established production in China
- taxes on components needed for assembly

- inconsistent implementation of incentives
- uncertainty in off-take demand.

Supportive policies, quality standards, and results-based financing for locally assembled products are key to surmounting these barriers.



Fan customer in Bihar, India
Photo Credit: Monica Tiwari, SPI



Green Scene Energy founder Rekik Bekele in Ethiopia

THE APPLIANCE MARKET, THEN AND NOW

2.1 The off-grid solar appliance market in 2019

A LOOK BACK: WHAT DID THE OFF-GRID SOLAR APPLIANCE MARKET LOOK LIKE IN 2019?

By 2018, off-grid solar systems were already providing more than 73 million households (or 360 million people) globally with access to energy, and their reach was growing quickly.⁴⁸ The projected potential market for off-grid appliances was estimated at \$12.6 billion USD as of the end of 2018, anticipated to grow to 18.2 billion in 2025 and 25 billion by 2030. As three of the solar appliances most in demand at the time were televisions, fans, and refrigerators, the SOGAM report focused on those as a proxy for overall off-grid household appliance trends. These were the most advanced solar off-grid appliances with respect to technological maturity during this period, although all markets were nascent.⁴⁹

While comprehensive data on off-grid appliance sales was unavailable in 2019, manufacturer's self-reported data suggested that, in aggregate, sales for key appliances grew by 50% to 80% annually between 2016 and 2019. However, this was against the backdrop of extremely limited sales at the beginning of the tracking period. Television and fan sales, in particular, were gaining momentum at this time. Refrigerators were generating interest from consumers but were not yet affordable enough to enable distribution at scale.

In terms of technology, solar appliance manufacturers were focused on efficiency improvements. This was most evident for televisions, where Global LEAP Awards test data showed a 45% improvement in efficiency between 2014 and 2017. Efficiency gains for fans were more modest, at approximately 10% from 2015 to 2017. However, further improvement was expected with the adoption of brushless DC (BLDC) motors and blade design innovation. For refrigerators, innovations in brushless DC motors, variable-speed compressors, and insulation materials and designs (e.g., phase-changing materials) held the most promise.

Consumer affordability was the most significant barrier to the growth of the off-grid appliance market. In India in 2019, microfinance institutions (MFIs) were the driving force in access to off-grid appliances. In sub-Saharan Africa, meanwhile, PAYGo financing offered an affordable entry point for appliance access to low-income consumers in markets with high mobile money penetration (e.g., Kenya, Rwanda, and Uganda). The lack of financing for off-grid appliances in countries like Ethiopia and Nigeria constrained the growth of the market in those areas.

The report also found that while governments were working to change or create policies to favor off-grid solar expansion, off-grid appliances were not explicitly included in those efforts.

Based on these findings,⁵⁰ the 2019 report closed with four expectations for the next decade:

- **Market size growth:** The report estimated the cumulative market opportunity across televisions, refrigerators, and fans at \$12.6 billion USD globally in 2018. It predicted that the market would double, reaching a \$25 billion USD opportunity by 2030 due to increased affordability, declining appliance prices, and better access to consumer financing.
- **Increased investment and innovation:** Continued product innovation and scale-up of sales operations were expected to drive down costs by an average of 30% by 2025, significantly increasing market competitiveness and consumer affordability.
- **Policy and regulatory support:** Implementation of supportive policies and efficiency standards was projected to increase the market adoption rate of off-grid appliances by up to 50%, enhancing overall market growth.
- **Household reach expansion:** The off-grid appliance market was anticipated to enable approximately 50% in growth in the number of households benefiting from off-grid appliance access, bringing the total to almost 60 million households by 2030.

2.2 The off-grid solar appliance market in 2024

WHAT HAVE WE LEARNED SINCE 2019? HOW HAS THE SOLAR APPLIANCE MARKET CHANGED?

In the past five years, the off-grid solar appliance sector experienced headwinds that made it difficult to achieve the optimistic projections of the 2019 report. Like many other industries, it has experienced a prolonged period of uncertainty.⁵¹

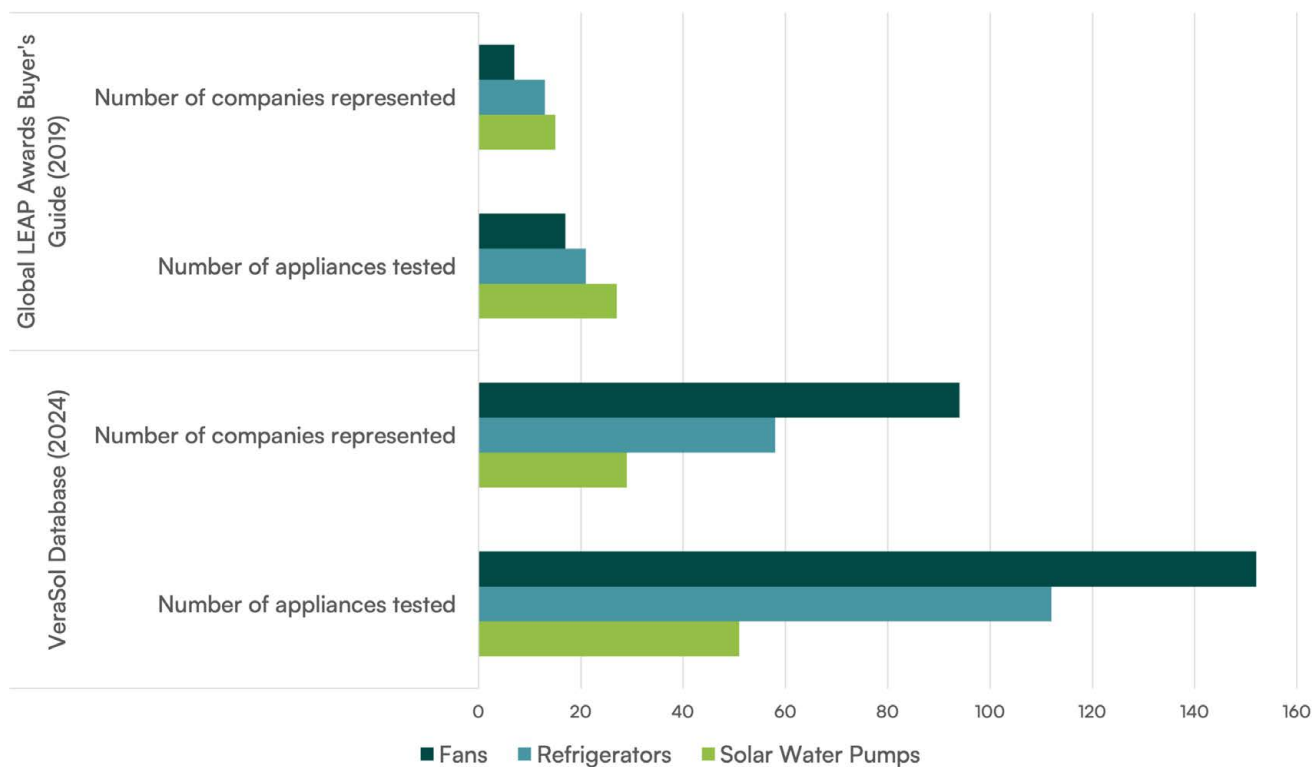
During the COVID-19 pandemic, progress towards improving energy access through off-grid solar products largely stalled. After the pandemic, the sector’s growth faltered in many core markets. Moreover, high inflation and depreciation of local currencies led to significant challenges for many off-grid solar companies as revenue (in local currencies)

eroded in value against debt repayments (in international hard currencies).

Notwithstanding these challenges, the sector has recorded notable gains since 2019. Using the number of companies participating in the sector as a proxy for market expansion, we tracked growth by comparing the numbers of companies and product models tested in the Global LEAP awards for SWPs,⁵² fans,⁵³ and refrigerators⁵⁴ against the number of those appliances tested and listed on the VeraSol database in 2024, as shown in Figure 7. An online survey of manufacturers and distributorsⁱⁱ also indicates that approximately 200 companies are presently involved in the off-grid solar appliance sector.

ii Reviewed GOGLA and GDC membership. These numbers do not represent unique companies per category, as some companies appear across all categories (domestic appliances, consumer electronics, productive use appliances).

Figure 7: Growth of appliance models and companies between 2019 and 2024



The off-grid solar appliance sector has also witnessed growing interest from donors and funders. For example, in 2018, nine donors supported EforA coalition programs and initiatives spanning 26 different countries and 19 off-grid and weak-grid appropriate technologies. Today, the coalition has 21 donor members, while its programs and initiatives span 65 countries and 34 key technologies.

Figure 8 characterizes the current global market maturity of appliances based on the best available quantitative data, such as the number of companies engaged in the sector, global sales volumes, performance data collected from lab and field-testing products, and the investment support directed towards the sector.⁵⁵

This categorization also considers qualitative data

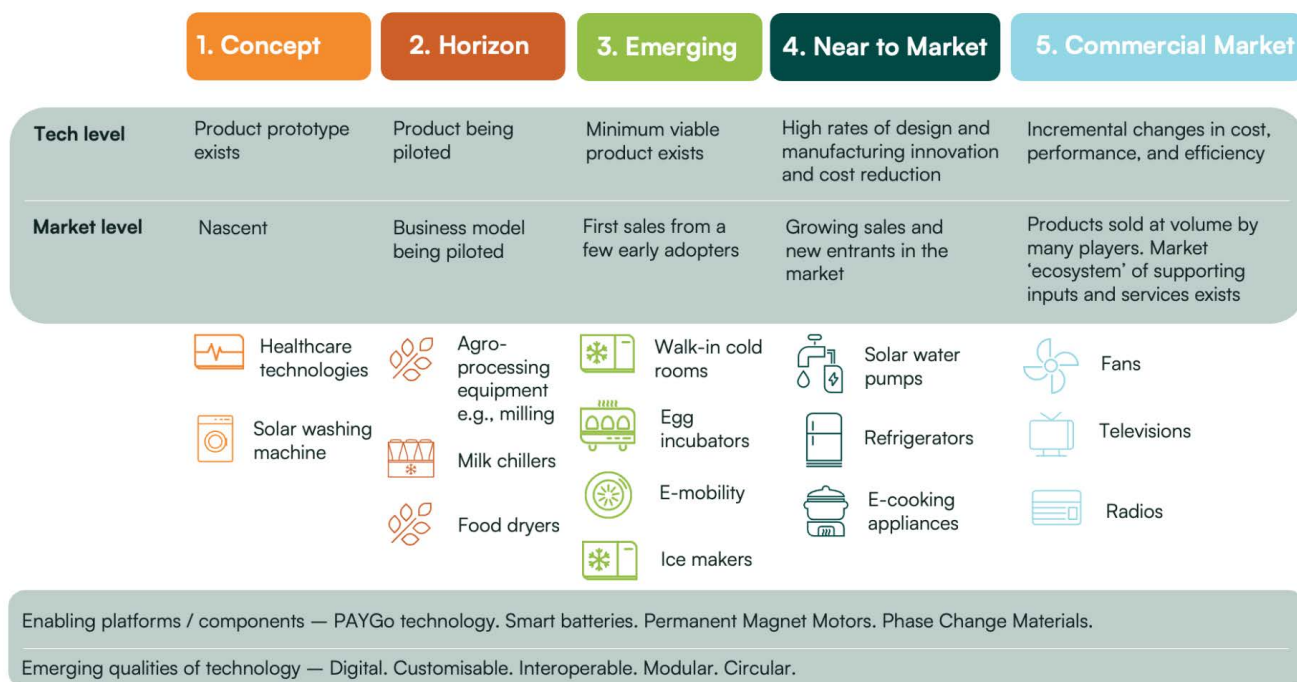
from sources such as stakeholder interviews and on-the-ground learnings.ⁱⁱⁱ Though this is a subjective grouping, it is useful in communicating relative maturity, characterizing the market for similar product classes, and identifying next steps for the sector.

Televisions, fans, and radios are classified as commercially mature appliances due to the widespread availability of the technologies, the presence of numerous distributors, and the availability and ease of repair and maintenance.

As more communities fall into heat stress, fans continue to lead the demand for off-grid solar appliances, with more than 1 million units sold annually since 2022.⁵⁶

iii Though included within the market characterization graphic, e-cooking appliances and e-mobility are not necessarily solar appliances. However, we have counted them among the priority appliances due to their significant potential to lower greenhouse gas emissions and improve livelihoods.

Figure 8: Global market maturity of off-grid solar appliances based on quantitative and qualitative data^{iv}



iv This figure is adapted from the *Off-Grid Solar Market Trends Report 2022: State of the Sector*. World Bank, October 2022.

To date, more than 150 models of fans from 94 brands have had their performance tested and published in the VeraSol database, illustrating the relative scaling of this technology and advances in performance evaluation. Therefore, this edition of the report continues to highlight this household appliance.

For the first time in the State of the Off-Grid Appliance Market series, our research scope has expanded beyond household appliances to product categories with greater potential economic and climate impact. Motor-driven agro-processing equipment (e.g., milling, hulling, and threshing appliances) is a horizon technology with a significant potential to impact entire communities. Offering new possibilities for income generation and improved livelihoods in rural areas, it is ideally used at the community level rather than by individuals, serving a multitude of users or customers in a relatively small area.

Moving further up on the market maturity scale, refrigerators and SWPs are now categorized as near-to-market appliances. While not as

commercially advanced as fans with respect to sales volumes, robust testing methodologies have been developed to evaluate their efficiency both in the lab and in the field. To date, test results for 112 refrigerators and 51 water pumps have been published on the VeraSol website.

Refrigerators and water pumps share a number of commonalities. They are highly customizable, with SWP specifications determined by crop-specific water needs, climate, weather patterns, and water resources and refrigerator technologies changing for different use cases. For both appliance categories, quality, durability, and thus warranties vary significantly across technologies and markets. Both are also currently unaffordable to large sections of the rural, off-grid populations who need them, impeding distribution at scale.

The next sections will extrapolate trends reported from three leading markets—India, Kenya, and Nigeria—to provide indications on the state of the global solar appliance market today and the outlook for the coming years.



Solar-powered irrigation user in India
Photo Credit: Bimala Colavito



Solar-powered refrigerator customer in Uganda

MARKET CHARACTERIZATION

3.1 Off-grid solar appliance sales trends

Since 2019, GOGLA, Lighting Global, and Efficiency for Access have been collecting data from affiliate companies every six months via an online survey. Although information collected from affiliates cannot be extrapolated to the entire sector, it provides the broadest, most reliable dataset available for the off-grid solar appliances sector. Participating companies voluntarily share data on their product specifications and sales volumes on a per-product, per-country basis. Data are self-reported by companies but are subject to thorough quality control and aggregation processes to ensure robustness of the insights and protect the confidentiality of companies' information.⁵⁷

These data show that over the last five years, sales of off-grid solar appliances have been reported in at least 92 countries, with sales mostly concentrated in a few countries: India, Kenya, Nigeria, Pakistan, and Uganda.^v

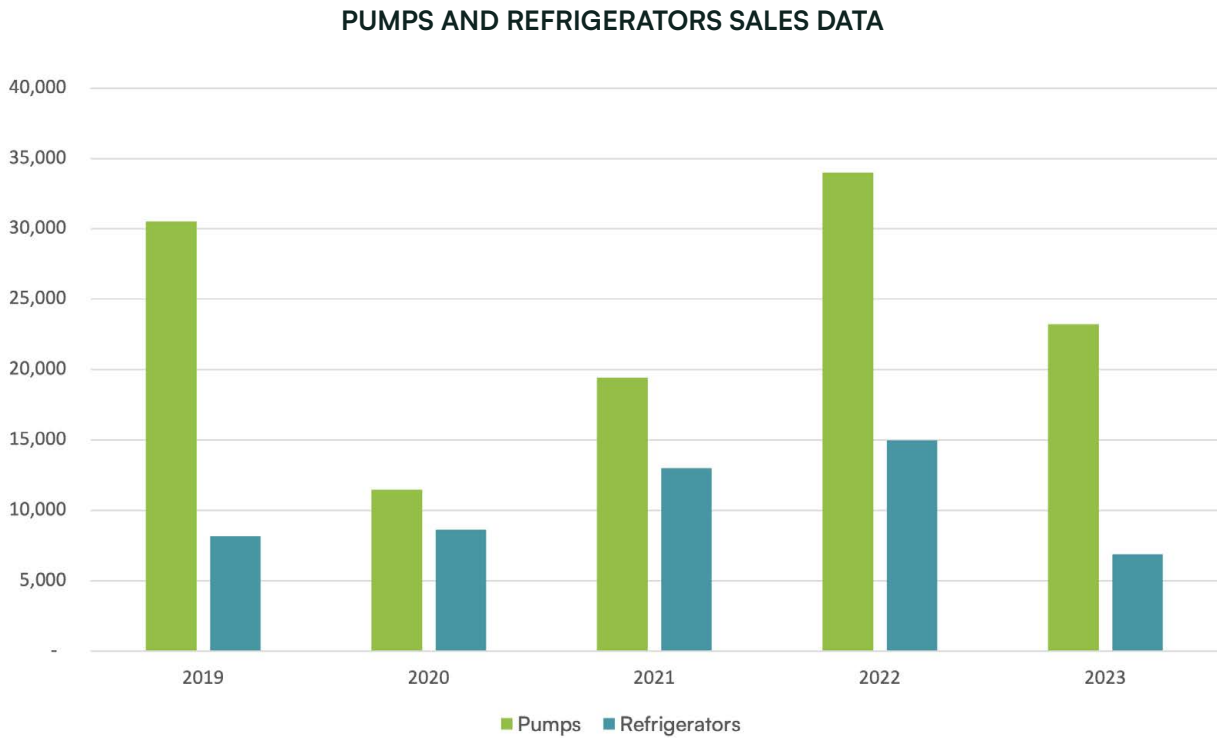
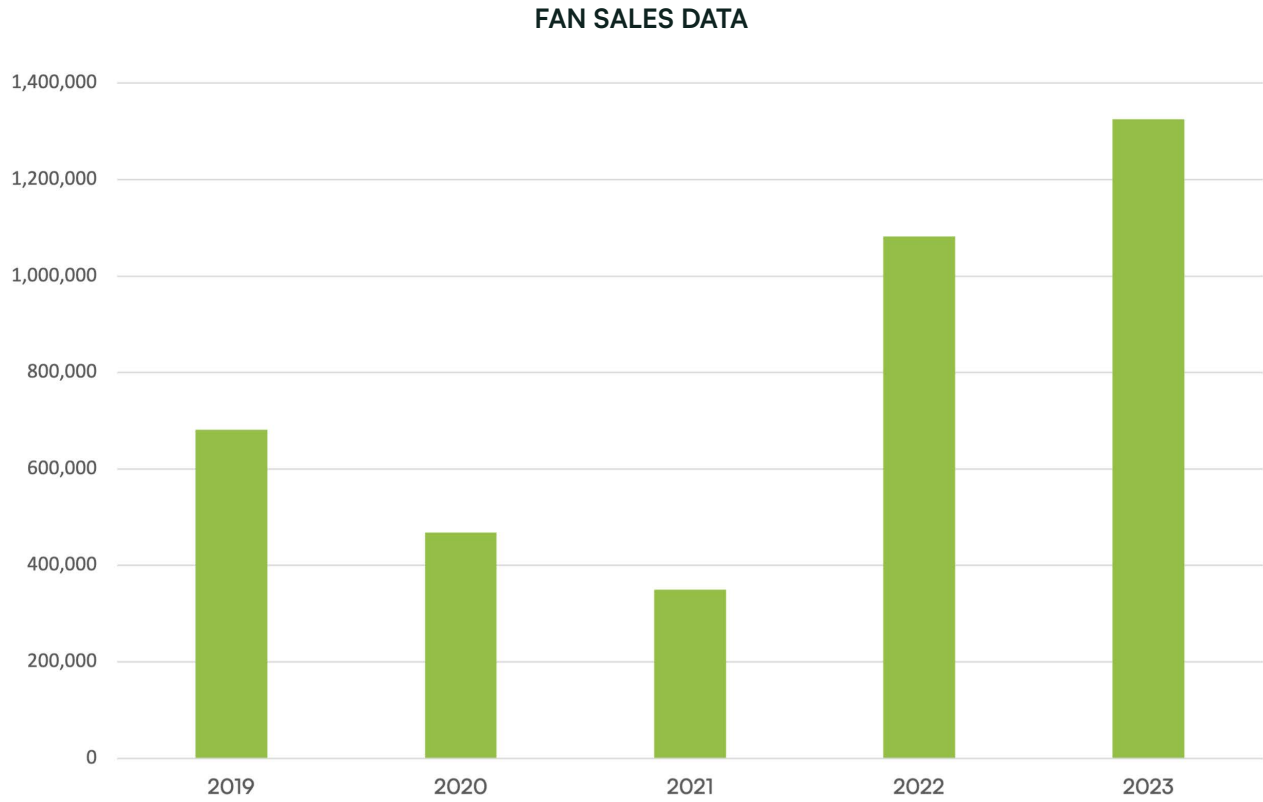
The most recent sales reports indicate a recovery of the sector, with the aggregated sales of fans, refrigeration units, and solar water pumps reaching 1.35 million units in 2023, up from 1.13 million in 2022.⁵⁸ As mills are a horizon technology, sales are still few and not yet being reported; thus, they are not represented in Figure 9.

v GOGLA sales data tracking 2018–2023. Although solar appliances are regularly sold in places such as the US and Australia, GOGLA focuses only on markets in the Global South.



Solar-powered fan users in Cumilla, Bangladesh

Figure 9: Reported sales of fans, pumps, and refrigerators from 2019 to 2023⁵⁹



The data show that fans have generally maintained a positive trend, with year-on-year growth since 2021. The sales trend is more mixed for pumps and refrigerators, with the highest sales so far being reported in 2022 before a contraction in 2023.

Not all distributors are GOGLA affiliates; thus, some may not report sales. Improving country-level data through market scoping surveys can help refine the sector's understanding of the sales trends.

FANS

Fans remain the leading solar appliance with respect to sales, which can be attributed to their relative affordability, portability, low energy needs, and ability to leverage distribution models used to deploy off-grid solar kits.

However, fan sales are not evenly distributed, but rather are concentrated in very few markets—namely, Bangladesh, India, Nigeria, and Pakistan—that have an outsized influence on the reported numbers.

South Asia remains the dominant market for fans, accounting for 61% of sales in 2023,⁶⁰ which can be attributed to the scorching, humid climates across many countries in the region. Some South Asian grid-connected households with unreliable connections have also purchased solar fans to provide cooling during frequent power outages.

As fans are relatively inexpensive, most South Asian households save to pay for them in cash, unlike more expensive cooling appliances (e.g., air conditioners) for which installment plans are available. Component-based fan sales are the norm in the region; fans are not typically bundled with solar energy kits.⁶¹

In sub-Saharan Africa, fan sales are driven by West Africa, and specifically Nigeria, whose fan penetration rates within off-grid rural communities are nearly five times higher than those of other off-grid rural communities in other nations.⁶²

Because many rural areas in sub-Saharan Africa aren't connected to the grid, 93% of fans sold there are bundled with a power system, usually a Solar Home System (SHS). Ninety-three percent of fan sales

occur via PAYGo SHS.⁶³

SOLAR WATER PUMPS

Solar water pump (SWPs) sales have largely been driven by increased consumer awareness and interventions by development programs. Affordability, however, remains the largest barrier to scaling.

Development initiatives supporting these appliances include:

- India's Pradhan Mantri Kisan Urja Suraksha Evam Utthaan Mahabhiyan Scheme (PM-KUSUM^{vi}):⁶⁴ Launched in 2019, PM-KUSUM aims to replace existing diesel pumps with solar-powered ones, benefiting individual farmers by subsidizing the installation of standalone solar agriculture pumps with capacities of up to 7.5 HP as replacements for diesel pumps in off-grid areas. As of October 2022, over 152,000 solar pumps have been installed under this initiative.⁶⁵
- Uganda Intergovernmental Fiscal Transfer Program (UgIFT) Micro-Irrigation project:⁶⁶ As part of Uganda's National Irrigation Policy, the UgIFT project supports the government's goal of expanding irrigated land by 2040. It offers farmers subsidies covering 25% to 75% of irrigation equipment costs for plots up to 2.5 acres.⁶⁷ To date, at least 60 systems have been installed in Mubende district, significantly aiding small-scale irrigation efforts.⁶⁸
- Solar Irrigation in Rwanda (SIR):⁶⁹ SIR helped farmers in ten Rwandan district irrigate maize and horticulture crops. Farmers are organized into groups based on their proximity to the irrigation system, with each group utilizing solar systems designed to irrigate one to ten hectares using surface water. Between February 2018 and November 2020, SIR assisted 1,450 farmers in adopting these systems.
- The Sustainable Energy for Smallholder Farmers (SEFFA) in Ethiopia, Kenya, and Uganda:⁷⁰ This initiative focuses on enhancing energy access among smallholder farmers to boost agricultural productivity.

vi KUSUM subsidized both on and off-grid pumps, with the bulk of the subsidy directed towards on-grid pumps.

Despite the successes achieved by these programs, the adoption of SWPs has been significantly limited by the high cost of irrigation pumps.⁷¹ This points to the need for sustained interventions to eliminate the affordability barrier by subsidizing the cost of the appliances.

Another barrier to faster scaling of the appliance is perceived risk. Many customers have legitimate

concerns around durability, access to repair services, and access to markets for the crops a new pump might allow them to grow (particularly if they have little experience with these crops). Financing is also a concern, given the perceived risk of taking a loan to purchase a pump. These concerns can be alleviated through increased consumer awareness campaigns and by incentivizing the adoption of quality-assured products.



Farmer setting up a solar-powered sprinkler near Siaya, Kenya
Photo Credit: Futurepump

REFRIGERATORS

Price remains the most significant barrier for refrigerator sales. Refrigerating units have the highest retail price of the four off-grid solar appliances discussed in this report, yet the target market has little disposable income and limited access to finance.

In a consumer impact survey of solar DC refrigerator owners in Kenya, Tanzania, and Uganda, 50% of respondents reported having to make unacceptable sacrifices to afford refrigerator payments. Twenty-eight percent of customers said they sometimes cut back on consumption to make repayments, while two percent said they regularly do so.⁷²

An interesting insight shared by stakeholders was that consumers prefer 150 to 250L refrigerators. The high cost of solar DC refrigerators in this size contributed to a consumer preference for AC refrigerator units. Rather than buying an expensive DC model, many people purchase a highly efficient AC refrigerator coupled with an inverter, thus investing in a larger photovoltaic (PV).⁷³ Interventions and mechanisms such as carbon finance, business model innovation, results-based financing (RBF), and product innovation must work together to lower the cost of solar DC refrigerators and enable the growth of this segment.



Solar-powered refrigerator user in Jinja, Uganda

GRAIN MILLS

Grain milling is one of the most common agro-processing activities across sub-Saharan Africa. A number of factors have limited the scaling of solar mills.^{vii}

One is a long history of reliance on manual and diesel milling,⁷⁴ necessitating a transition to new technologies by customers and mill operators, which can be time consuming. Another challenge is that milling is associated with lower-value crops such as grains and cassava. In addition, the market has few companies that are working to optimize both the technology and their business models, as well as identifying where to set up grain mills to achieve the utilization rates required for profitability.

BARRIERS TO SCALING

For all four appliances studied for this report, a range of barriers hinder sales, from affordability to consumer awareness, business models, and appliance capacity (since although customers are known to prefer larger sizes, distributors stock smaller sizes). Access to finance is a challenge for both end-users and distributors, with the global economic shocks of the past five years having made investors more risk-averse. Some companies have exited the market due to increased costs and risks of doing business. Financial strain has also reduced many consumers' ability to pay for solar appliances, further dampening the sector's growth.

vii CrossBoundary estimates that approximately 90M tonnes of maize are milled annually across 500,000—750,000 mills in Sub-Saharan Africa, the majority of which are diesel powered.

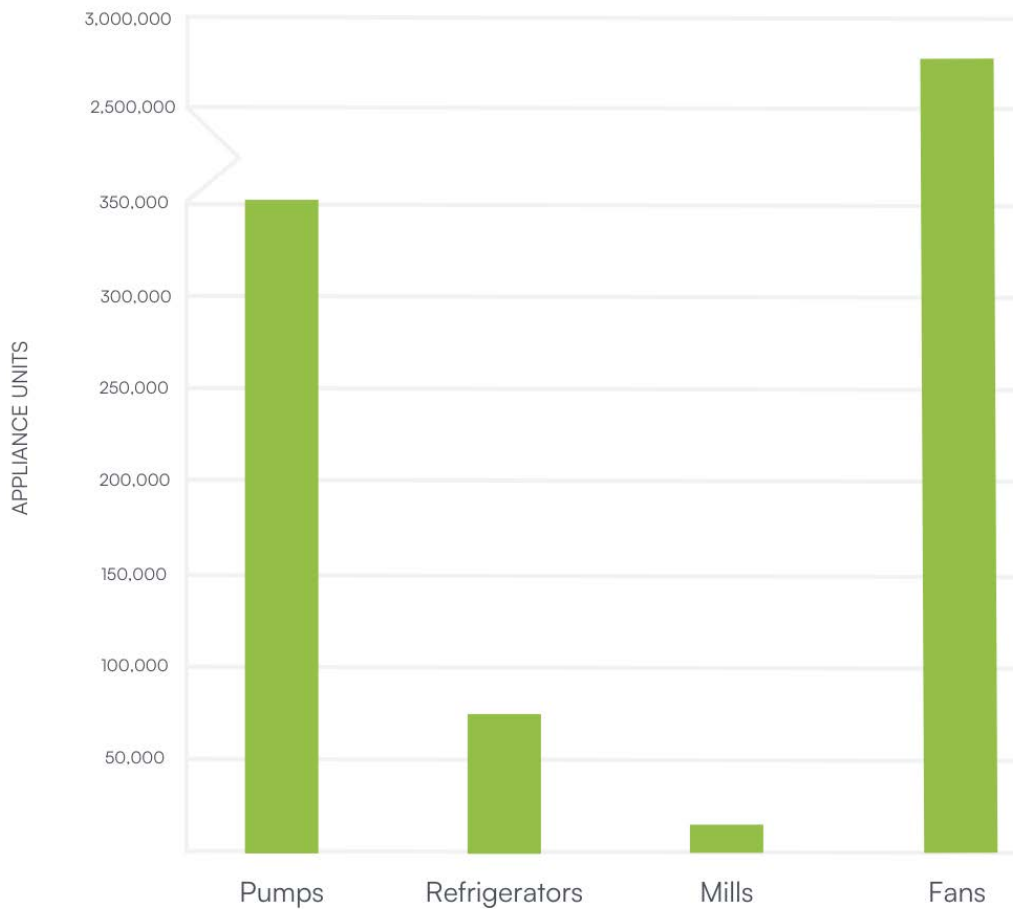
SALES ANALYSIS

To estimate the cumulative sales of the appliances in scope, we made the below assumptions to extrapolate the sales per appliance:

- For SWPs, we assumed the reported sales by GOGLA affiliates represent only 33% of all sales.
- For refrigerators, we assumed the reported sales by GOGLA affiliates represent 75% of all sales, as the complexity of the technology implies that a large informal market is less likely.
- For fans, we reduced the total sales reported by GOGLA affiliates by 33% because most reported sales are concentrated in a few South Asian countries and some of those are happening in grid-connected households. We therefore interpolated to estimate sales targeted at the off-grid populations.
- For mills, as there were no formal reported sales, we assumed that every year approximately 2,500 solar mills were sold.

We estimate that approximately 3.1 million units of the off-grid solar appliance categories in scope were sold exclusively to off-grid populations globally between 2019 and 2023. The breakdown of the total sales is as follows: fans (86%), pumps (11%), refrigerators (2%), and mills (1%), as shown in Figure 10.

Figure 10: Cumulative global sales of solar powered appliances between 2019 and 2023



Using a household size multiplier of four people per household,^{viii} we estimate the potential impact of off-grid solar appliance sales to date as follows:

- People benefiting from improved water access due to accessing a solar water pump: 1.4 million
- People experiencing improved livelihoods from owning a refrigerator (particularly women and

children, who otherwise spend large parts of their day procuring fresh food and cooking): 272,000

- People in off-grid areas currently accessing cooling services from off-grid fans: 12 million
- Entrepreneurs benefiting from offering solar-powered milling services: 12,500
- Households benefiting from non-polluting milling: 250,000

^{viii} Our modeling showed the average household size for India, Kenya, and Nigeria to be 4.4 people. Based on this, when extrapolating for global numbers we used a lower, more conservative number than the 5.5 figure often used in the more commonly cited Impact Assessment Framework.

3.2 Addressable and serviceable market

We estimated a significant addressable market opportunity of \$58 billion USD for the four key appliances and a serviceable market of approximately \$12 billion USD (21%), as shown in Table 1. This indicates a massive opportunity for growth as well as an urgent need to close the appliance access gap for the world's unelectrified population.

ADDRESSABLE MARKET

We employed a conservative approach to modeling for the addressable market by limiting the analysis to off-grid populations. However, we recognize that for the populations living in areas with unreliable power supply, off-grid solar appliances offer an alternative to diesel as well as a backup in case of grid failure. In India, for instance, the highest demand for solar appliances will likely be in weak-grid areas. As a result, the estimates above are conservative and assumed to be within the lower range, although they



Solar panel installation
Photo Credit: Simusolar

still provide an indication of the considerable market potential for solar appliances.

We estimated that for solar water pumps, refrigerators, and mills, sales are less than 2% of the global serviceable market. Fan sales are slightly higher, with

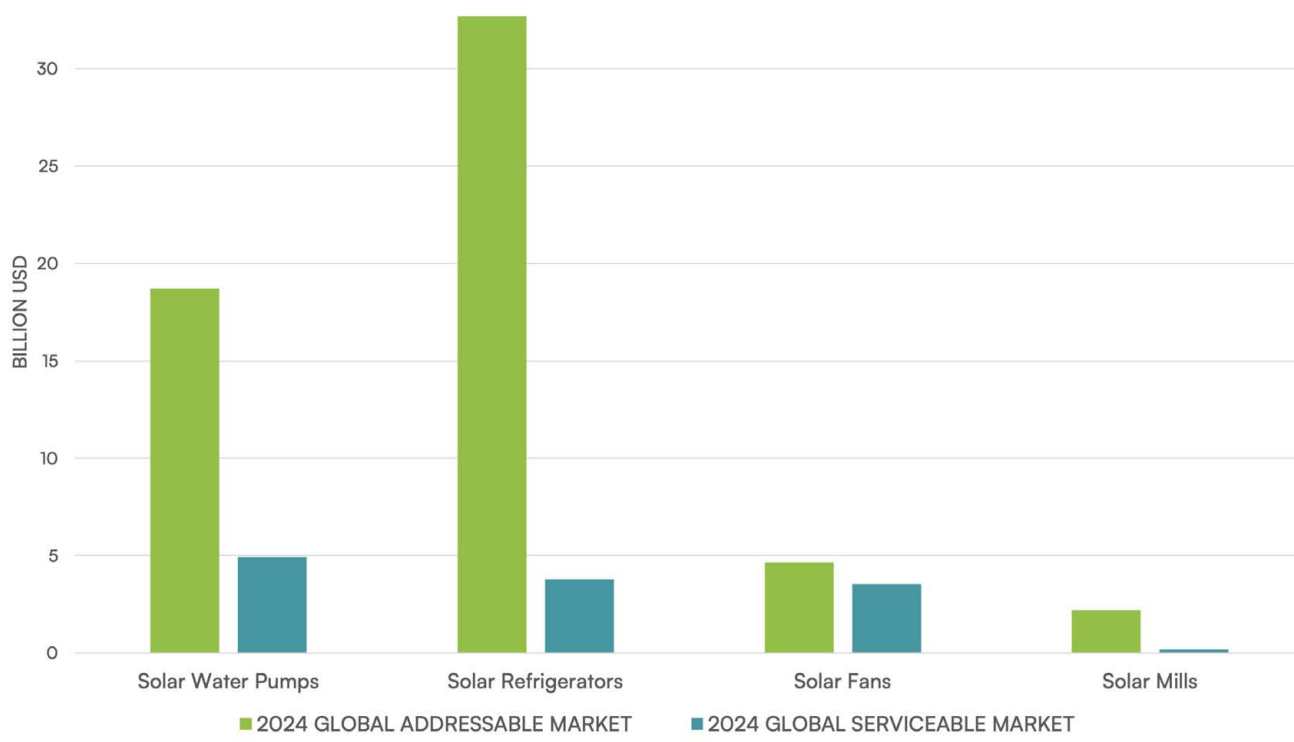
sales estimated to be 4% of the serviceable market.^{ix}

^{ix} Fans are a low-cost cooling appliance that can offer relief in extreme temperatures, although they are not the best solution for all situations. There continues to be a gap in available, affordable, and contextually appropriate space cooling technology, highlighting a need for innovation.

Table 1: Estimated global addressable market for solar powered appliances

	2024 GLOBAL ADDRESSABLE MARKET (BILLION USD)	2024 GLOBAL SERVICEABLE MARKET (BILLION USD)
Solar Water Pumps	18.71	4.94
Solar Refrigerators	32.67	3.78
Solar Fans	4.66	3.54
Solar Mills	2.21	0.19
Total	58.25	12.45

Figure 11: Comparison across four solar off-grid appliances (water pumps, refrigerators, fans, and mills) between the global addressable market and serviceable market



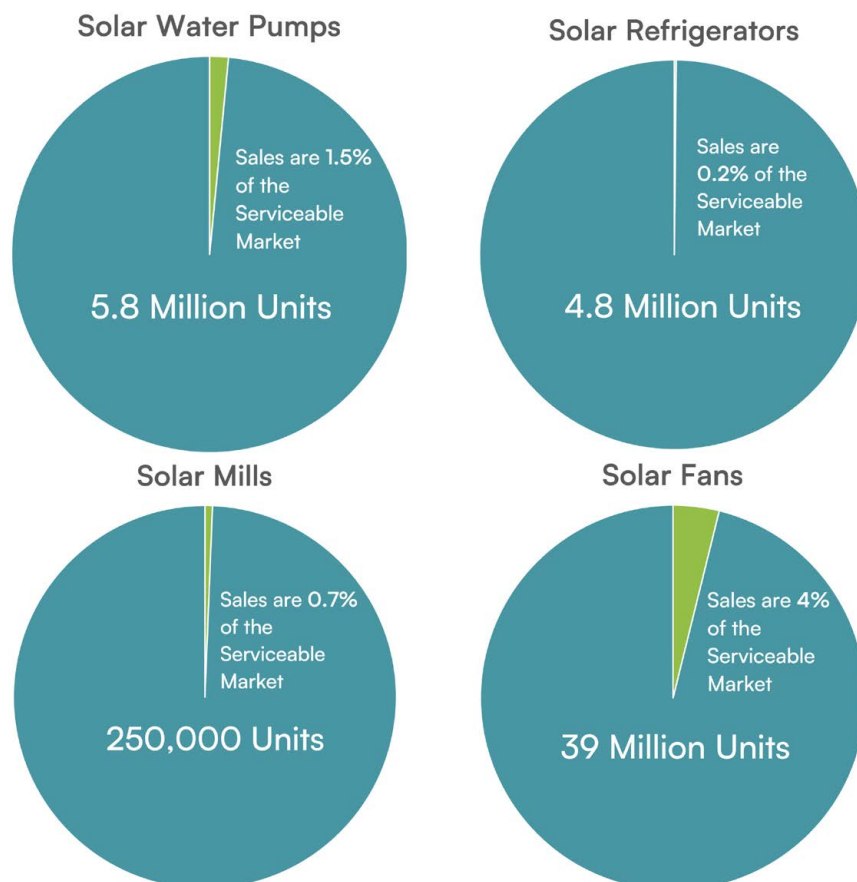
This demonstrates the amount of scaling required to close the gap between sales and the serviceable market, as shown in Table 2. Previously discussed factors such as low consumer awareness, limited access to funding, supply chain challenges, and affordability contribute to this slow market growth.

Table 2: Global appliance sales vs. serviceable market sizes

	2023 SALES (UNITS)	2024 GLOBAL SERVICEABLE MARKET (UNITS)	SALES AS A PERCENTAGE OF THE SERVICEABLE MARKET
Solar Water Pumps	90,800*	5,863,000	1.5%
Solar Refrigerators	7,500	4,836,000	0.2%
Solar Fans	1,576,000	39,305,000	4.0%
Solar Mills	1,600	250,300	0.7%
Total	1,677,000	50,254,000	

x These estimates do not include the MNRE-reported SWP sales in India because our analysis excludes weak-grid and focuses on standalone pumps (generally below 3kW).

Figure 12: Percent sales of the serviceable market per appliance

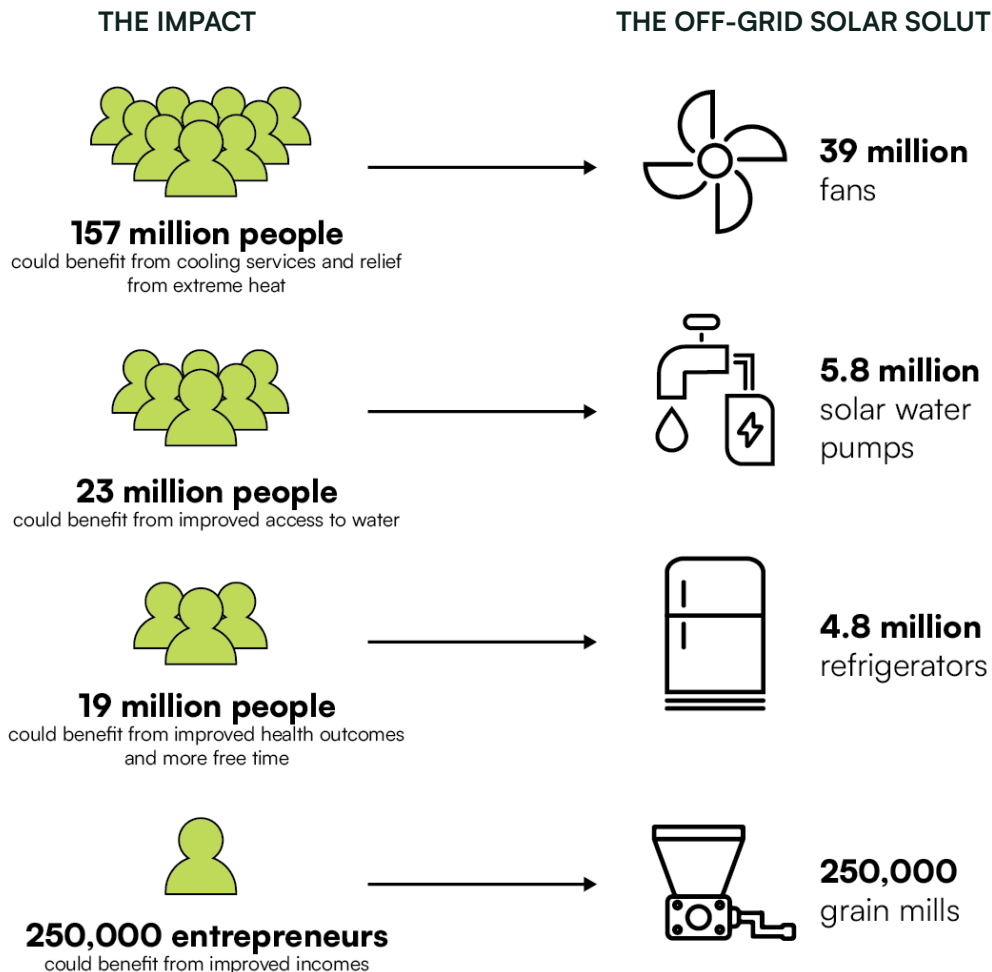


If the serviceable market were completely served by 2030, we estimated the following potential impact of off-grid solar appliances, as shown in Figure 13:

- 23 million more people would benefit from improved water access through accessing to a solar water pump.
- 19 million people would experience improved livelihoods from owning a refrigerator, as it frees up time, particularly for women and children, who otherwise spend large parts of their day procuring fresh food and cooking. In healthcare settings, refrigerators are also critical for storing vaccines and medicines, directly impacting community health outcomes.
- 4.8 million more people could increase their incomes by owning refrigerators, which have been shown to generate additional income by opening new business opportunities like the sale of cold beverages.
- 157 million people would have access to cooling services and relief from extreme heat by owning off-grid fans.
- 250,000 entrepreneurs would see increased income from offering solar-powered milling services, while five million households would benefit from cleaner milling operations. These solar-powered mills would eliminate the risk of diesel fumes contaminating the milled products

Figure 13. Potential impact of off-grid solar appliances

HOW INNOVATIVE OFF-GRID SOLAR SOLUTIONS CAN BRIDGE THE GLOBAL ENERGY ACCESS GAP



and reduce exposure to exhaust emissions for both millers and consumers.

We also assessed how the total sales to date (i.e., cumulative sales) compare to the addressable market for appliances in the off-grid population and

found that only 2% of the addressable market has been reached with present sales. The off-grid solar appliance market is growing, but not rapidly enough to close the energy service access gap by 2030, as shown in Table 3.

Table 3: Cumulative sales vs. global addressable market

	CUMULATIVE SALES 2019 —2023 (UNITS)	2024 GLOBAL ADDRESSABLE MARKET (UNITS)	PERCENT OF MARKET REACHED
Solar Water Pumps	356,000	36,366,000	1.0%
Solar Refrigerators	68,000	37,962,000	0.2%
Solar Fans ^{xi}	2,705,000	81,110,000	3.3%
Solar Mills	12,500	3,743,000	0.3%
Total	3,142,000	159,181,000	2.0%

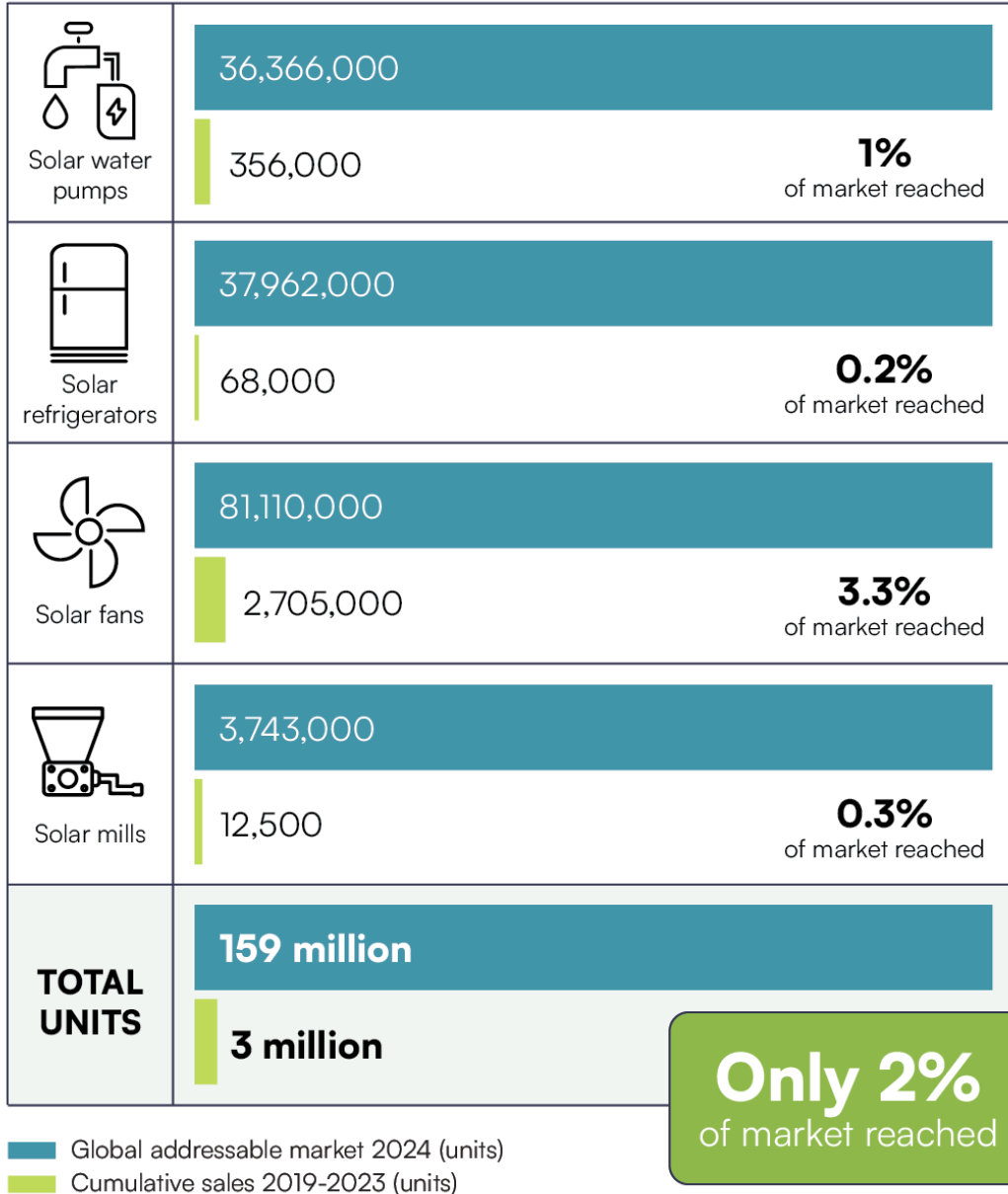
xi Estimated total fan sales for exclusively off-grid communities.



Farmwarehouse team and customers gathered around a solar-powered Farmwarehouse grain mill in Nigeria

Figure 14: Global addressable market versus cumulative sales (2019–2023)

SOLAR APPLIANCES PERCENTAGE OF MARKET REACHED



Consumer affordability and access to capital for product innovators and distributors remain the most significant constraints in scaling the off-grid solar appliance sector. External economic factors like foreign exchange (FOREX) constraints, inflation, and local currency devaluation also significantly affect retail prices, impacting affordability. Further, appliances are not always readily available where

off-grid populations are located due to infrastructure gaps that impact access and distribution. In addition, consumer awareness of off-grid solar appliances remains low.

The model assumes the financing arrangements and appliance prices indicated in Table 4 to estimate the serviceable market.

Table 4: Appliance prices and payment terms^{xii}

	APPLIANCE PRICES	PAYMENT TERMS
Solar Water Pumps	\$843 to \$966 USD	23% down payment, 18 months installments, 30% interest
Solar Refrigerators	\$782 to \$1,186 USD	10% down payment ^{xiii} , 11 months installments, 22% interest
Solar Mills	\$766 to \$1,116 USD	23% down payment, 18 months installments, 30% interest
Solar Fans^{xiv}	\$55 to \$90 USD	20% down payment, 5 months installments, 40% interest

xii We arrived at price ranges based on stakeholder interviews in India, Kenya, and Nigeria as well as web searches comparing retail prices. We used the lower price ranges found in each market to get a sense of affordability. This implies that for appliances that are more expensive than the range shown, the affordability is even lower. We based payment on appliance distributors' reports of existing financing options in the market.

xiii This was modeled based on existing appliance financing terms in local currency for refrigerators in Kenya.

xiv For India and the broader South Asian market, the model assumes cash purchase terms for fans.

SERVICEABLE MARKET

The serviceable market (in terms of units) is only 32% of the addressable market. This varies widely across appliance categories, with pumps at 16% of the addressable market, refrigerators at 13%, mills at 7%, and fans at 48%. For the bottom 20 access-deficit

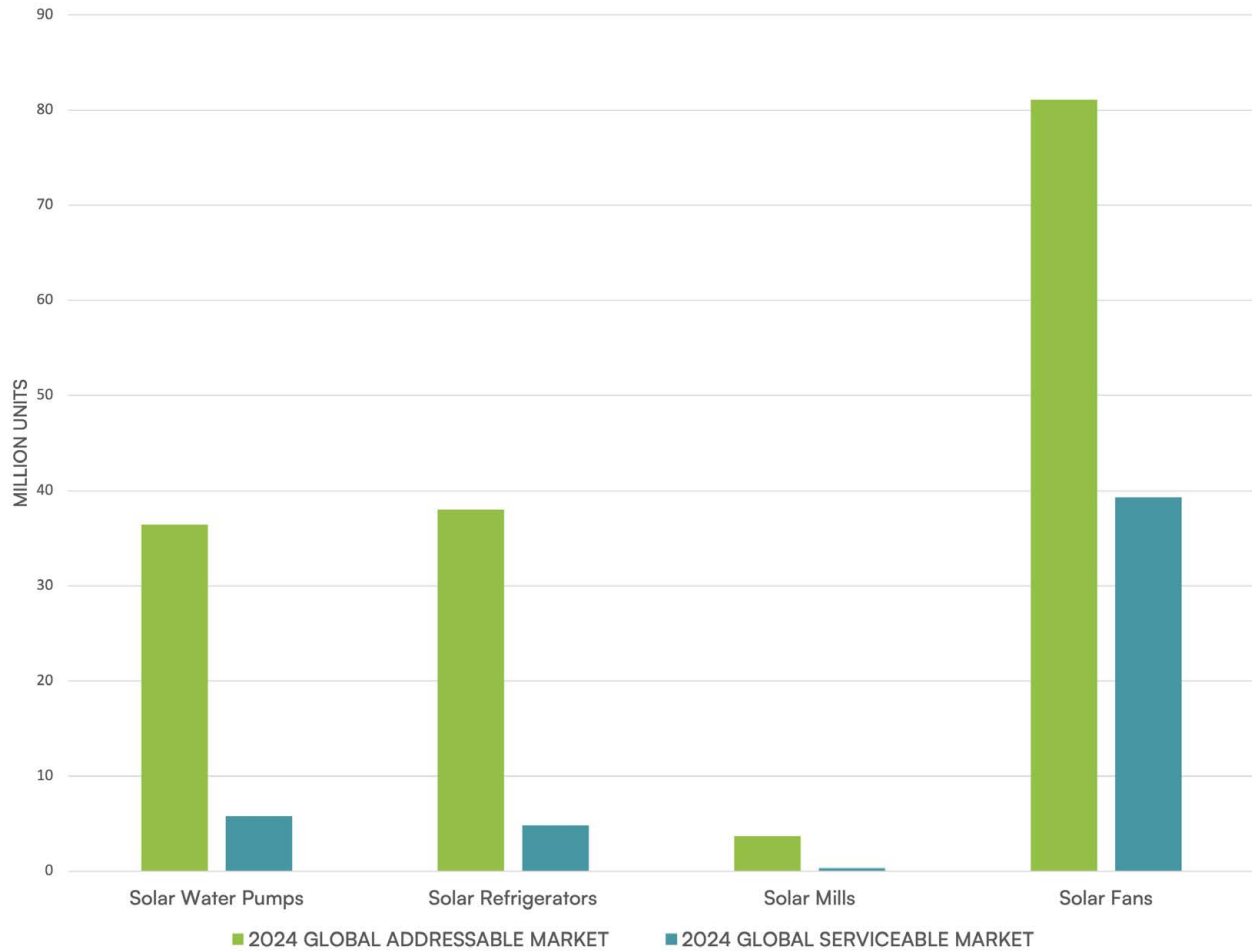
countries, the payment terms were modeled around the current terms offered in Kenya and Nigeria, as corroborated by stakeholder interviews.

The serviceable market as a fraction of the addressable market provides an indication of market maturity, as shown in Figure 15.

Table 5: 2023 Global addressable and serviceable markets in appliance units

	GLOBAL ADDRESSABLE MARKET (MILLION UNITS)	GLOBAL SERVICEABLE MARKET (MILLION UNITS)	PERCENT OF SERVICEABLE TO ADDRESSABLE
Solar Water Pumps	36.4	5.8	16%
Solar Refrigerators	38.0	4.8	13%
Solar Mills	3.7	0.3	7%
Solar Fans	81.1	39.3	48%
Total	159.2	50.3	32%

Figure 15: Estimated global addressable and serviceable market in million units per appliance



Fans, which are considered mature, have a larger serviceable market share (greater than 40%) compared to near-to-market appliances like pumps and refrigerators (approximately 15%). Horizon technologies such as mills have the lowest share (7%).

The difference between sales and the serviceable market signals supply-side constraints, with companies not being able to meet the demand for off-grid populations who are estimated to be able to afford the appliance if purchased in installments. This

demonstrates a significant capital need requirement for companies to scale their distribution and increase production of the key appliances. The impact of flexible funding on companies has been recently demonstrated by the Appliance Financing Facility, discussed in the following case study.

Governments also need to develop infrastructure to support access to those populations and logistics serving them to ensure the appliances can reach them.

PRODUCTIVE USE APPLIANCE FINANCING FACILITY

In October 2022, CLASP and Nithio launched the Productive Use Financing Facility (PUFF) with funding from the Global Energy Alliance for People

and Planet (GEAPP). This \$6.5 million USD initiative, which ended in July 2024, aimed to make productive use appliances (PUAs) more affordable for consumers and companies in emerging markets. The facility was active across the off-grid, mini-grid, and grid-connected sectors, operating in Democratic Republic of Congo, Ethiopia, Kenya, Nigeria, Sierra Leone, and Uganda.⁷⁵ To date, it is the only large-scale, multi-country RBF that has focused on productive use appliances with a funding mechanism structured around the challenges early-stage PUA market players face.

CLASP and Nithio identified seven appliance technologies to support through the facility—walk-in cold rooms, refrigerators, electric pressure cookers, electric induction cookers, fans, grain mills, and solar water pumps—based on their maturity and potential to drive development impact. Twenty-four companies participated in the program. The facility supported companies through the provision of procurement subsidies, capacity-building grants, debt financing, and advisory support. Additionally, its operations were designed to generate foundational data on



Green Scene Energy employees in Ethiopia

appliance market activity and developmental impacts, enhancing knowledge of appliance performance, national markets, and consumer satisfaction.

The initiative saw several successes:

- Subsidies had a direct, immediate commercial impact, leading to immediate increases in sales volumes and velocity. Many companies leveraged their subsidy allocations to raise additional funding or launch entirely new lines of business. Companies participating in the PUFF pilot increased their sales by an average of 1,165% compared to the previous year.
- For the participating companies, business revenues rose 61%, from an average of \$376 USD to \$604.9 USD per month. Eighteen percent of businesses hired at least one additional employee.

Key learnings from the program highlight growing appliance market participation due to increased maturity in the off-grid solar market; donor investments; technology and business model innovations; and expanded quality assurance efforts. However, appliance markets remain early-stage, with

affordability being a significant barrier to rapid sales growth. Companies still face challenges in accessing financing and achieving sales growth needed to realize the potential of scaling business lines.

Another key lesson was that external shocks had a chilling effect on sales, with currency volatility and supply chain disruptions posing significant challenges for participating companies. Products took substantially longer to arrive in-country than anticipated—30% of participating companies had supply chain delays of three to six months—and swings in currency valuations disrupted some companies’ balance sheets while they waited for stock to arrive.

Despite these constraints, PUFF successfully stimulated the sale of more than 10,000 of the key appliances in scope. ■

Table 6: Reported sales of appliances in research scope by companies supported by PUFF as of June 30, 2024

	REFRIGERATOR/ FREEZERS	GRAIN MILLS	FANS	SOLAR WATER PUMPS	TOTAL
Kenya	519	31	0	1,997	2,547
Uganda	338	1	0	943	1,282
Democratic Republic of Congo	0	0	5,644	0	5,644
Nigeria	582	81	0	0	663
Ethiopia	0	0	0	209	209
Sierra Leone	57	0	0	0	57
Total	1,496	113	5,644	3,149	10,402

The large gap between the serviceable and addressable markets highlights the challenge of limited affordability, as these appliances are needed by low-income groups. This gap requires massive amounts of funding to provide consumer subsidies and ensure no one is left behind.

The Energy Savings Trust report *The Road to Zero Interest* offers concessional consumer financing (CCF) as one of the potential demand-side subsidy mechanisms that can address this gap by offering zero or low-interest loans to consumers over a five-year repayment period.⁷⁶ We modeled the CCF case in Kenya to demonstrate the potential impact on the serviceable market and illustrate the significance of end-user subsidy schemes on appliance affordability. The results are presented in Table 7.

Seventy-four percent of the customers interviewed by 60dB for its *Why Off-Grid Energy Matters 2024* report bought their appliances using some form of payment plan or loan.⁷⁷ During stakeholder interviews, appliance distributors report that down

payments are their biggest indicator of repayment rates. As a result, they typically require expensive down payments of at least 20% of the appliance retail price, which presents an insurmountable obstacle for many potential buyers who could otherwise afford the installment payments.

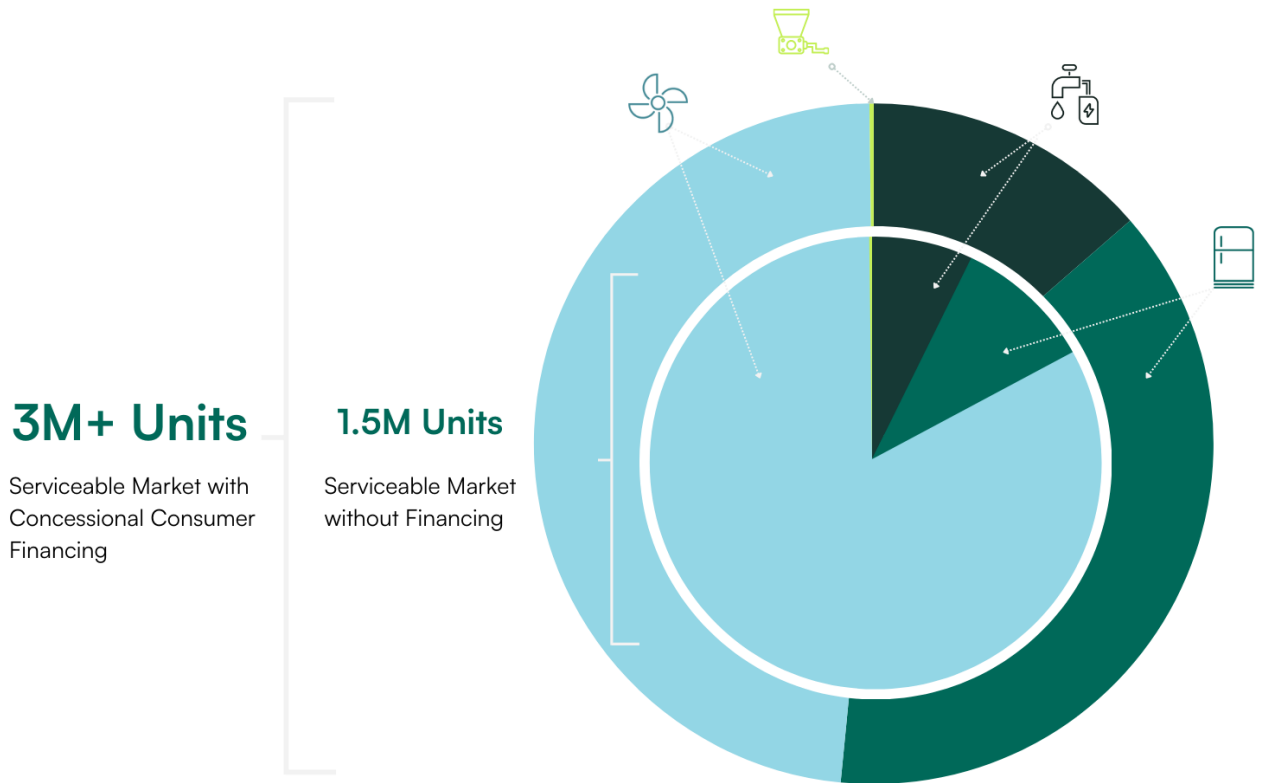
These constraints raise the possibility of customers being overindebted because of appliance purchases. Further, increasing the proportion of payment plans and loans while lowering the deposit amount might increase the risk of customers being overindebted, as well as raise questions about what recourse should be taken in instances of default.

These results show that concessional consumer financing substantially improves affordability, nearly doubling the serviceable market and increasing sales. The most notable impact can be seen with refrigerators, as they are the highest-priced appliance category and are not constrained by external factors such as value chains and water access.

Table 7: End-user subsidy impact on affordability in the Kenya solar appliance market

SOLAR APPLIANCE	SERVICEABLE MARKET (UNITS)	CCF SERVICEABLE MARKET (UNITS)
Water Pumps	115,000	414,000
Refrigerators	156,000	1,154,000
Fans	1,300,000	1,468,000
Mills	3,000	7,100
Total	1,574,000	3,043,000

Figure 16: Comparison between serviceable market with concessional consumer financing versus without financing for off-grid solar fans, mills, water pumps, and refrigerators



Devidayal employee operating a solar-powered refrigerator in India

3.3 Market sizing methodology^{xv}

To estimate the global addressable and serviceable markets for the four off-grid solar appliances in scope, we developed market sizing models for India, Kenya, and Nigeria using country-specific data, then extrapolated that to estimate global off-grid solar appliance access needs. We termed this total number the addressable market.

Our market-sizing models estimated appliance needs by using the latest available country data, as well as assumptions based on historical trends where data were not readily available, to estimate the addressable off-grid market.^{xvi} The approach involved a detailed value chain analysis and a sector-specific evaluation to quantify production volumes and the number of rural, off-grid smallholder farmers.

For water pumps, the availability of water was a key consideration to avoid over-abstraction. Thus, the model considered the number of smallholder farmers who would have access to surface water and groundwater. We also considered the size of the farm and the suitability of the crop grown.

For refrigerators and fans, we specifically considered the rural off-grid population in each country that does not have access to these appliances. The

additional assumption for refrigerators was that households could use them to generate income by storing and selling products like beverages.

For mills, we focused on the main cereal or grain per country and the volumes produced by smallholder farmers. The mill was assumed to be a shared appliance used by at least 20 households within a two-kilometer radius.

To evaluate affordability, we first calculated the monthly household income from the total national income. We accounted for income variations by using the World Bank's income quintile data. Additionally, we included a statistical correction for rural income across each quintile because rural off-grid households typically hold less income than their urban, grid-connected peers. We then modeled illustrative installment purchase terms per country and appliance to understand what segment of the population could afford the appliance, thus estimating the serviceable market.^{xvii}

The total addressable and serviceable markets, expressed in terms of the number of appliance units, were then multiplied by the price of each appliance to estimate the market value in US dollars. Figure 17 illustrates the methodology for the country-specific market sizing models.

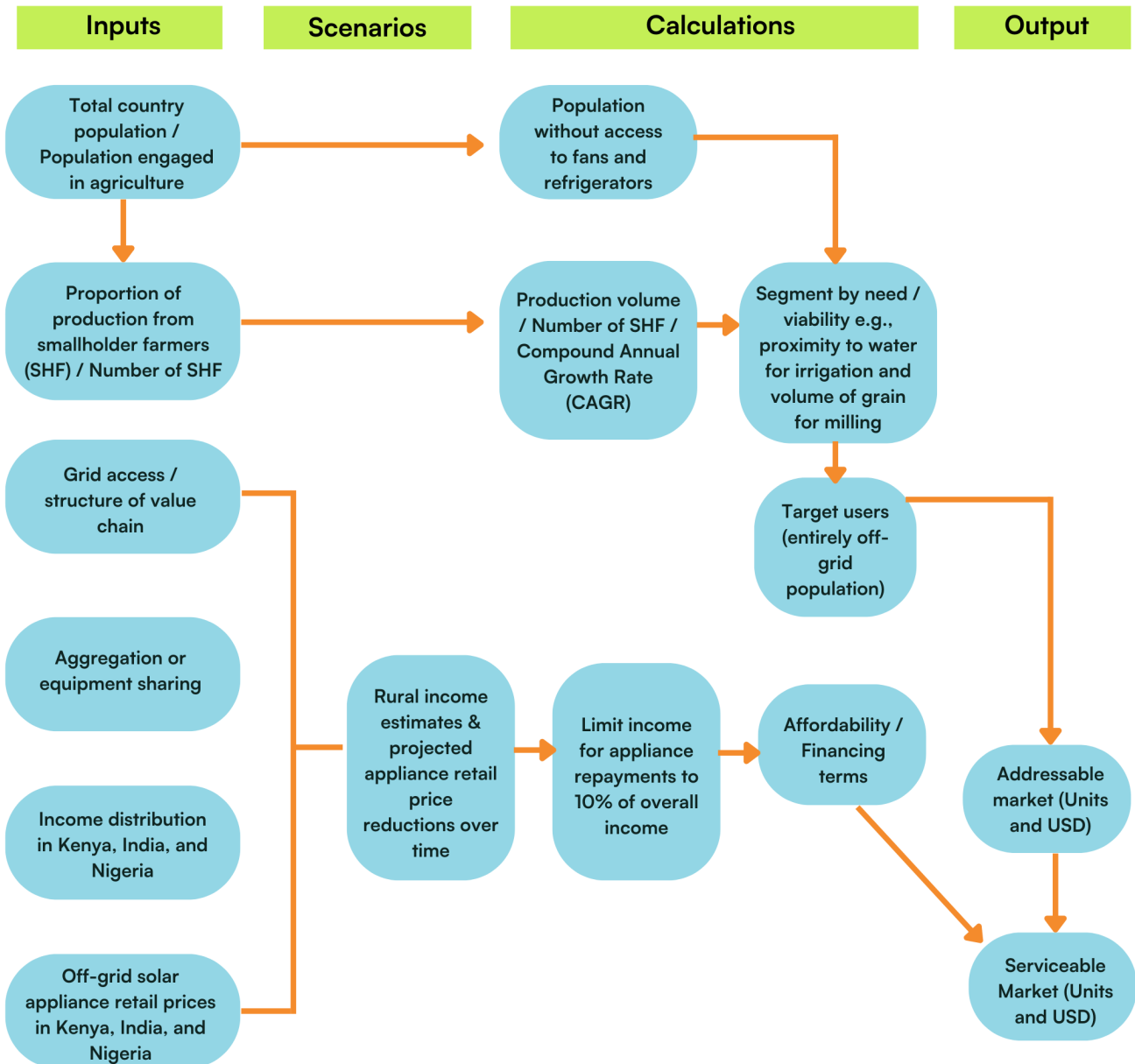
xv The market sizing models for India, Kenya, and Nigeria, as well as the global extrapolation data sheets, are provided as an annex to this report.

xvi Though weak-grid households are also potential customers for solar appliances, the model takes a conservative view and sizes exclusively for off-grid populations.

xvii This approach could be further improved by embedding two more variables: an assumption regarding access to appliances (i.e., distance to a major distribution center) as well as service models to complement the installment plan payment models.

Figure 17: Logic behind the country-specific addressable and serviceable market model

METHODOLOGY FOR MARKET-SIZING MODELS



GLOBAL EXTRAPOLATION

Our calculations for India, Kenya, and Nigeria estimated that there are at least 22 million unelectrified households in these countries. This figure accounts for 15% of the estimated 154 million off-grid households globally. We then used linear extrapolation for each appliance category, embedding the same constraints in the country models (such as access to water for pumps and shared appliances for mills) to compute the global addressable market.

To assess global affordability, we used the World Bank Poverty and Inequality Platform to generate average incomes by quintile for the top 20 access deficit countries, since retail prices and income vary so widely. We then added the serviceable market for each of those countries, which represents 74% of global off-grid households. We also included a statistical correction for rural income across each quintile and used linear extrapolation for each appliance to estimate the global serviceable market.



Irrigation, India

KEY MODEL ASSUMPTIONS

- **Household estimate:** The total number of households living in off-grid areas is estimated to be 153 million, or 685 million people. We augmented this with reported population growth projections over a ten-year projection period.
- **Income and financing considerations:** Smallholder farmers and rural populations generally have low disposable income, which potentially reduces their ability to purchase off-grid solar appliances upfront without some interventions to lower the cost or provide an alternative enabling payment over time. Our model therefore considered appliance financing to represent the highest potential pathway to acquisition for rural consumers.
- **Repayment assumptions:** We assumed that customers would commit a maximum of 10% of their monthly income towards the repayment of the appliance. This limits the risk of over-indebtedness given the low income of rural households.
- **Sizing for solar milling machines:** To size for solar milling machines, we used the grain or crop most prevalently grown in a given nation as proxy: maize in Kenya, cassava in Nigeria, and rice in India. For the global extrapolation, we used smallholder maize production as the proxy for milling needs.
- **Fan and refrigerator demand:** We assumed that all off-grid households that don't currently own a fan or refrigerator would want one. We sized the demand based on population and access to electricity, independent of any value chain.
- **Future demand forecasting:** To forecast future demand, the model considered projected grid extension rates, growth in income due to increased productivity from acquiring an off-grid solar appliance, and the possibility of reduced appliance prices because of technology maturation and economies of scale.



Woman using a fan to cool off

3.4 Technology trends

The continued improvement of technologies offers promise for both the expansion and improvement of energy services for people around the world. Efficiency for Access reports have demonstrated the advances in efficiency, quality, and lower costs with which those services were delivered between 2021 and 2023.^{xviii}

xviii For a detailed explanation of the technology improvements for each appliance in scope, please see Efficiency for Access Tech Trends 2023 series: <https://efficiencyforaccess.org/publications/2023-tech-trends-in-energy-access/>

This section provides high-level insights into some of the key technological enablers for the four appliances studied in this report.

Increased affordability and innovation in solar technology are transforming the appliance market. The IEA reports that the declining costs of solar PV modules and battery technologies, combined with modular system designs and innovative consumer financing, are increasing the affordability of solar systems and displacing alternatives such as fossil fuel generators.⁷⁸ Battery costs are expected to decline,⁷⁹ which will contribute to a further reduction in the overall price of solar energy systems.



Solar panels in Kenya

RELIANCE ON DIESEL GENERATORS AND THE SHIFT TO RENEWABLE ALTERNATIVES

In certain off- and weak-grid markets in South Asia and sub-Saharan Africa, many users rely on diesel generators, commonly referred to as gensets, to power their AC appliances. Small enterprises are particularly accustomed to this power source. According to a 2021 report, there are seven million backup diesel genset sites in sub-Saharan Africa today, producing energy equivalent to 120 coal-fired power stations and costing users \$13 billion USD in fuel each year.⁶⁰ These small fossil fuel-burning gensets also create significant noise and climate pollution.

While small-scale standalone solar home systems are available in these markets, they are less competitive because AC appliances are often more affordable and widely available than DC appliances.

The Zero Emission Generators (ZE-Gen) initiative has taken meaningful steps to replace fossil fuel-powered generators with renewable energy-based alternatives.^{xix} To achieve this goal, ZE-Gen is trying to tackle market failures, accelerate innovation, and start crowd-in financing. At the 2024 Transforming Energy Access (TEA) Forum, it announced a collaboration with the Green Genset Facility (GGF),

xix More information on the ZE-Gen initiative: <https://www.ze-gen.org/ze-gen/>

which aims to help distributors buy solar-powered generators from suppliers, addressing the lack of accessible, affordable working capital that is considered the biggest obstacle to these purchases.

Increased proliferation and continued technological advancement in solar PV, batteries, and gensets will stimulate further adoption of solar appliances. Zero-emission solar generators can enable greater access to energy services at a lower financial, environmental, and societal cost. Early movers such as Sun King, Amped Innovation, Biolite, and Power Oaks are already piloting and selling solar energy generators that range from 0.5 kW to 2 kW.

APPLIANCE-SPECIFIC TECHNOLOGICAL ADVANCEMENTS

BRUSHLESS DC MOTORS

Improving electric motors' efficiency and performance will significantly impact solar appliances, as these motors are the "prime movers" for nearly all appliances that require motion. Brushless DC motors (a type of permanent magnet motor) have been leveraged for solar appliances because of their low starting current, tolerance for lower voltages, and higher efficiency, enabling longer runtime for a given amount of energy.⁸¹



BRUSHLESS MOTORS

Two former grant recipients of the Efficiency for Access Research & Development Fund illustrate the remarkable impact of brushless motors on efficiency, which translates directly to cost savings.

- In cooling, Harness Energy⁸² developed a super-efficient rechargeable 12V brushless DC motor pedestal fan widely used in Pakistan. Given that Pakistan experiences almost seven months of heat or extreme heat (50 degrees Celsius, or 122 degrees Fahrenheit) each year, the country remains the world's second largest market for solar fans after India. One customer reported that electricity bills at their furniture store decreased from \$21 to \$13 USD within two months of owning the higher-efficiency solar fan.⁸³ This highlights how improvements in technology, and consequently efficiency, can decrease the cost of space cooling for millions of people, making it more accessible.
- In agro-processing, Agsol has used a custom brushless DC motor to optimize the power consumption and performance of its new milling machine, MicroMill.⁸⁴ The company reports that the MicroMill is 2.5 times more efficient than other small electric mills, with a throughput of 55 kilograms per hour (kg/h) for fine flour and 250 kg/h for chicken feed. ■



PM Motors, Pakistan

REFRIGERATION

Light commercial applications remain the most viable market for off-grid refrigerators. Freezers and multi-temperature units^{xx} are becoming more popular because they offer higher potential for income generation in small business settings. Refrigeration units have shown promising advancements in efficiency, with an average improvement of 5% observed between 2019 and 2022.^{xxi} Component-specific challenges persist, including the limited number of manufacturers of DC compressors and the optimization of these compressors.

A key advancement in refrigeration technology is the use of thermal energy storage to reduce the need for electrical batteries, lowering the cost of solar systems to operate a refrigerator while making the system more durable and resilient in off-grid conditions.

xx Multi-temperature units are refrigerators that provide the ability to store frozen, semi-frozen, and chilled products in a single refrigerator.

xxi Models tested since 2021 are listed on the VeraSol Product Database, <https://verasol.org/>.

Making use of phase change materials (PCM), also known as thermal batteries, these thermal energy storage systems have increasingly replaced traditional battery technologies while maintaining low temperatures even during power cuts or solar PV intermittency periods. PCMs are often part of solar direct-drive (SDD) technologies, which eliminate the need for electrical batteries (usually the weakest point in the system), resulting in reduced energy usage and lower operating costs for consumers. Vacuum insulated panels (VIPs) for heat-loss prevention have been shown to improve energy performance by up to 30% in refrigerators, although they are not standard material used for insulation and can be expensive.^{85, 86}

There has been a notable proliferation of thermal storage across major solar refrigerator manufacturers. Expanding from the pioneering use of this approach by established players such as SunDanzer and SureChill to develop vaccine refrigerators, new players like Amped Innovation, Devidayal, and Koolboks are now incorporating the technology.



Koolboks, Nigeria

AMPED INNOVATION

There are no large multinational appliance companies developing off-grid solar refrigerators for rural Africa or Asia. One of the main barriers to serving this market with high-efficiency solar refrigerators has been the technical difficulty of maintaining cold temperatures while accommodating frequent turnovers of produce in hot, humid environments. Affordability is another major challenge, as solar fridges are too expensive for many people who need them.

Amped Innovation (Amped), a grantee of the EforA Research and Development Fund, has developed a solution that addresses both issues.

The company's first solar refrigerators were modular, enabling it to test different configurations and use cases with end users. Customers provided feedback that its initial product, which allowed for a range of 20–200Wh of lithium ferro phosphate (LFP) battery and 40–160W of solar panels, wasn't powerful enough, given its limited runtime after sunset. However, since batteries are the most expensive component of solar refrigerators, Amped

needed a way to increase power without raising consumer prices.

To address these issues, the company opted to test a phase change material (PCM) "ice battery" approach. PCMs absorb heat as they melt and can be "recharged" through cooling until they crystallize and release the stored energy back into the environment. Amped harnessed this property to develop a design that uses a combination of PCM geometry, a hybrid PCM alongside a LFP battery, and customized air circulation.

Focusing on specific design elements such as a custom refrigerator controller allowed Amped to ensure strong thermal control, holding within 0.5 degrees Celsius instead of the 10 degrees Celsius flux seen in other solar fridges. The company was also able to maintain comprehensive control of the compressor and all powered components within the fridge. Furthermore, it improved the drive train efficiency by 18% compared to the default controller supplied by a vendor. To ensure high performance in a hot, humid environment like Africa, Amped used a >100W compressor—twice as large as others on the market—to maximize cooling power. A "shelf storage" mode also allowed the fridge to remain in storage for over a year without any impact on battery life.

The design also targeted affordability, resulting in a \$160 saving for the end user. To further drive down costs, Amped used water in the PCM battery instead of a more typical specialized paraffin solution. It also incorporated affordable circuits and reduced the number of components in circuits. As a result, the final system retails at under \$735 (with PAYGo financing). This number is expected to fall under \$600 later this year as volumes increase.

The design also enables final assembly to occur locally, which could reduce costs through lower import duties and smaller shipping volume while creating new green jobs in rural areas. ■

INTERNET OF THINGS (IOT) AND PAYGO INTEGRATION IN SOLAR APPLIANCES

Across multiple appliance categories such as milling, refrigeration, and pumping, we observe increasing integration of IoT and PAYGo for multiple use cases, such as collecting data for electric cooking for carbon credits, improving preventive maintenance for appliances, and driving affordability for end users. Some examples of these applications include:

- Remote monitoring of real-time battery health and performance, enabling customers to preempt expected failures and maintenance, resulting in better service uptime and cost savings.
- BridgeWare by Omnivoltaic, a low-cost, customizable hardware piece for data communication to the cloud independent of the type of data network.

Concerns about interoperability persist, however. The lack of compatibility and interoperability between solar appliances and energy systems has locked some consumers into buying appliances from the same company. This also forces manufacturers to incur additional costs in adapting the communication protocols of their appliances to different hardware providers and eventually impedes the secondhand appliances market.

Notable innovations have been made to address this challenge, such as the development of standardized communication protocols and smart monitoring capabilities applicable across different appliance categories. Examples include:

- OpenPAYGo Link^{xxii} by Solaris Offgrid, which provides a standardized ecosystem to enable PAYGo integration in a wider range of appliances.

xxii Open Source Paygo communication protocol | OpenPAYGO Link | PaygOps <https://www.paygops.com/openpaygolink>

- GEN2 Smart Box by SureChill, which provides system monitoring and compressor driver protection for off-grid refrigerators. It enables integration with existing PAYGo solar home systems and is compatible with a wide range of DC compressors.⁸⁷
- Nexus Channel^{xxiii} by Angaza, which provides an open-source inter-device communication solution for PAYGo appliances.
- OpenPAYGo^{xxiv} token, an open-source software solution supported by EnAccess. This radio frequency identification (RFID)-based badge system activates PAYGo functionality. It enables a cost-effective system to extend the benefits of PAYGo products and services in areas without mobile money by enabling a much simpler and less error-prone customer journey, as well as the opportunity to unlock RBF for customers.

While significant progress has been made in enhancing appliance interoperability through interventions like the Connect Initiative,^{xxv} a major gap in hardware compatibility still exists. Advancements in this field are crucial to ensuring a fully optimized, compatible, and interoperable ecosystem for solar appliances.

Additional research and development funding is required to accelerate progress on technology. This is especially true for appliances in the concept and horizon stages of maturity, where enhancing efficiencies and driving down prices is critical.

xxiii Nexus Suite Overview | Angaza Nexus <https://developers.angaza.com/docs/dev-portal-nexus/m6eu9i6y5fOfi-nexus-suite-overview>

xxiv EnAccess Open-Source Materials <https://enaccess.org/materials/#hardware-software>

xxv The Connect Initiative by GOGILA aims to create an ecosystem where appliances are interoperable by defining a family of universal connectors and device-to-device firmware standards for enhanced interoperability of 12V SHS Kits and Appliances. <https://www.gogila.org/what-we-do/business-services-and-standards/the-connect-initiative/>



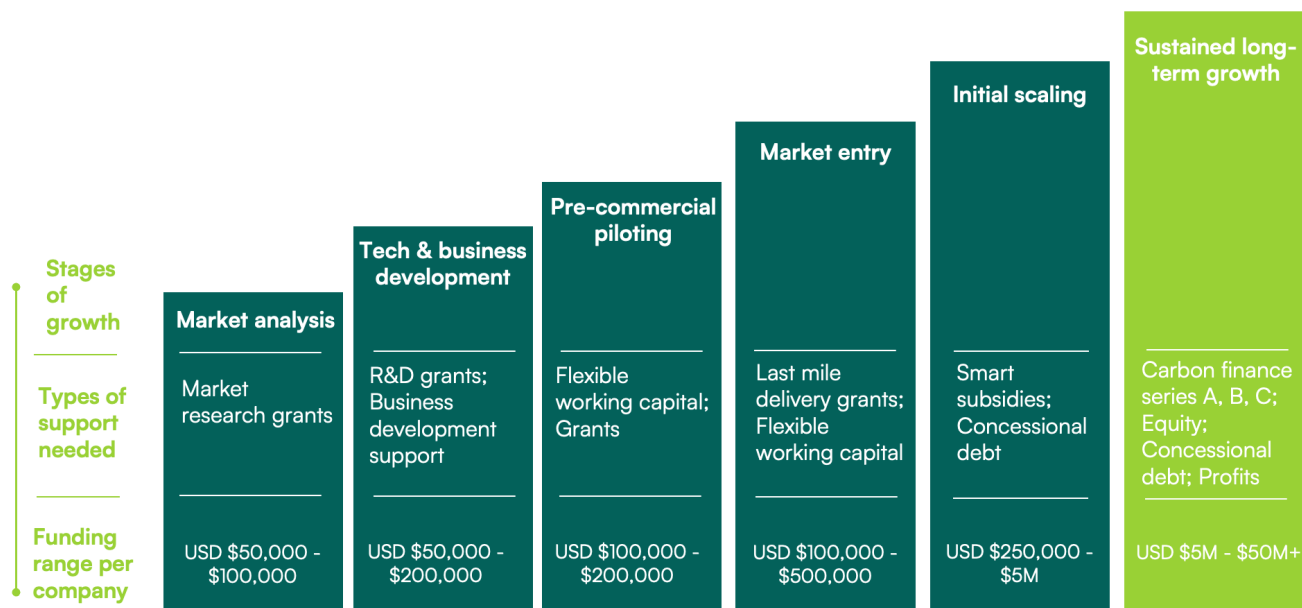
John Mbindyo, founder and CEO of cold storage provider FreshBox, in Kenya

3.5 Financing trends

The off-grid appliance market is characterized by a diverse set of companies with distinct financial needs. The myriad business models in the sector enable the sale of many different types of appliances with different end-users across a wide range of geographical and cultural contexts, with each aspect of the business model impacting how

companies finance their operations. Businesses operate in different segments of the value chain, partner with other organizations in different ways, and provide varied services as well as products to their customers. They are also at very different stages in the development of their business models and technology, encompassing everything from early-stage concepts to large companies selling a plethora of appliances across numerous geographies (Figure 18).

Figure 18: Illustration of off-grid appliance company growth stages ^{xxvi}



xxvi Note: This company journey is illustrative and was designed to demonstrate the journey of product technology customers and vertically integrated companies. It may not apply, therefore, to all companies at every link of the value chain.

ECOZEN SOLUTIONS

Ecozen Solutions (Ecozen), an India-based agritech startup, has successfully entered underserved markets in semi-urban and rural areas through its innovative products and technology-enabled solutions. Catering to the needs of farmers and agri-value chain players, it has developed products including Ecofrost, a solar-powered cold room with room storage capacity between two and thirty metric tonnes, and Ecotron, a smart controller for irrigation pumps.⁸⁸ Ecozen has also launched Eco-Connect, a platform connecting farmers with organized buyers, and Ecofrost Link, a modular and technologically

advanced version of Ecofrost.

In 2018, Ecozen received early-stage support from Efficiency for Access through the Global LEAP Awards,⁸⁹ enabling it to enter the Kenyan market for the first time, test its product with end users, and navigate significant logistical hurdles. The company also formed critical partnerships with organizations such as SokoFresh in Kenya.⁹⁰

More recently, Ecozen has secured significant funding from various investors, including IFA Fund, Caspian, and vos-Triodos Funds, as well as a \$25 million USD Series C equity and debt capital round in 2023 led by Nuveen and Dare Ventures (Coromandel Internation I). This has allowed Ecozen to expand its product range, increase production capacity, and enter new geographies, resulting in the company having the largest footprint of off-grid cold rooms in India and Africa (the latter demonstrating the importance of partnerships in this sector) and serving as a major supplier of solar water pumps in India.⁹¹

Ecozen's focus on sustainability and climate-smart solutions has helped it gain traction among agri-value chain players in India and Africa. The company aims to continue its growth trajectory by leveraging its innovative technology stacks and expanding its operations globally. ■



Ecozen walk-in cold storage unit in India
Photo Credit: Ecozen India

A company's stage of growth impacts the funding needed by and available to it. As a result, the financing landscape encompasses a variety of methods and investment instruments, catering to companies at different stages of growth and across various technology sectors. The exact amount of sector investment is difficult to estimate, however, since investment is allocated to some companies that focus purely on appliances and others where appliances are only one part of their portfolio.

This section explores the different financing avenues employed by companies in the off-grid appliance space and is structured around the purpose of different types of capital. There are two main categories:

- Capital for product and business model innovation and market expansion, which includes grants and equity
- Working capital, which comprises debt, securitization, project finance, results-based financing, and bulk procurement

CAPITAL FOR PRODUCT AND BUSINESS MODEL INNOVATION AND MARKET EXPANSION

GRANTS

Grants are typically non-dilutive forms of capital, meaning they do not require companies to part ways with their equity. Unlike debt products, they typically do not require any fixed repayment. As a result, they are considered a lower-cost method of financing, capable of supporting companies in the earlier stages, from market analysis, technology development, pre-commercial business development, and market entry. Development partners can deploy this form of financing to support markets with low off-grid appliance penetration and company presence.

Some grants may target early-stage research: specifically, market research or funding to support R&D for technology development. One example, the Global LEAP Awards, is discussed in case study 5 of this report. Another program that has enabled some companies to conduct research and develop early-stage innovations is the Innovate UK—funded Energy Catalyst program, which, as of July 2024, had provided over £160 million GBP official development assistance (ODA) funding to more than 300 projects in over 45 countries across Africa, Asia, and the Indo-Pacific.^{92,93} The program has a broad focus on energy access, with appliances representing only a portion of its portfolio.

Early-stage grants can also help seed new companies in certain undeveloped markets.

Results-based financing has also emerged as a grant-based mechanism that is heavily used in this sector to increase market penetration, though not directed for research purposes. These grants are often rolled out at the country level or through multi-country programs, as outlined in the enabling environment section of this report.

competition identifies and promotes high-performing technologies in energy-efficient appliances, with past funding focused on areas like cold chain, refrigeration, electric cooking, and e-waste.

Such programs demonstrate the performance of innovations in the sector, allowing other companies to adopt and refine them to scale up business models in-country, as in the Ecozen example discussed in case study 4 of this report.⁹⁵ ■

GLOBAL LEAP AWARDS⁹⁴

Sector-focused award programs have played a role in the development of off-grid appliance companies over the last several years. These may provide modest cash prizes, but more importantly focus on demonstrating best-in-class technology or projects within the sector.

One example is the Global LEAP Awards, which is organized by Efficiency for Access. This international



Electric pressure cooker user in Kenya

CORPORATE EQUITY

In recent years, established off-grid solar companies have successfully secured substantial equity funding rounds to continue distribution of off-grid solar energy kits and associated appliances. One example is SunKing's \$330 million USD Series D equity round of funding, supported by investments from M&G, General Atlantic, and Leapfrog.⁹⁶ This reflects a broader trend within the off-grid solar market in which larger companies attract increasingly larger investments, leading to a consolidation of investment capital. It also demonstrates a continuation of the trend of companies supplementing their existing business lines with new ones, including developing and selling new appliances. This trend, which is well-documented in reports such as the *Off-Grid Solar Market Trends Report*,⁹⁷ highlights growing confidence of investors in the long-term potential of the off-grid solar market, but also the continued challenge smaller companies experience in raising capital.

Established agricultural off-grid appliance companies also continue to leverage equity or equity-like financing to fuel their growth trajectories. As mentioned, EcoZen secured a \$25 million USD funding round comprising both equity and debt. In April 2024, SunCulture announced that it had raised a \$27.5 million USD Series B funding round, which included follow-on investment from existing investors Equator,⁹⁸ Infraco Africa, Reed Hastings, and The Schmidt Family Foundation. This continued access to equity financing underscores the potential viability of PUE business models and their ability to attract investment, though there have been few such large-scale equity investments in dedicated off-grid appliance businesses.

Some new entrants selling income-generating appliances have attracted earlier-stage equity financing, but this investment remains limited. Moving beyond the business models and appliance categories of off-grid solar companies, these dedicated, income-generating appliance companies have required capital to test their business models, expand into early markets, and develop production capacities. This spans investments into small-scale cold storage such as the \$2.5 million USD seed funding investment into Kooldboks led by Nigeria-based Aruwa Capital Management, Social Alpha's seed investment into Devidayal Solar Solutions in India, and Acumen's initial \$1 million USD investment in Promethean Power Systems and follow-in

investment into Promethean Power Systems via Acumen's Pioneer Energy Investment Initiative Plus (PEII+) fund.^{99, 100, 101, 102} Similarly, Oorja Development Solutions raised a seed round from Schneider Electric Energy Access Asia (SEEAA) and subsequent \$1.5 million USD pre-series A funding round to reach further customers with its solar irrigation model in India. SokoFresh raised capital from Acumen to continue building out its model of distributed cold rooms^{103, 104} and Stable Foods in Kenya raised \$600,000 USD from Mercy Corps Ventures and the Acumen Resilient Agriculture Fund (ARAF) to build its smallholder farmer platform, which includes irrigation-as-a-service.¹⁰⁵ This trend signifies the increasing attractiveness of the off-grid appliance market for entrepreneurs and the potential for new players to disrupt the sector.

FUNDING WORKING CAPITAL

CORPORATE DEBT

Similar to the trend in increasing equity investment, large and established off-grid solar companies continue to raise significant debt to finance inventory and receivables. Examples include SunKing's \$7 million USD debt facility from Lendable in early 2024 for solar home system inventory purchases¹⁰⁶ and BBOX's €11 million EUR deal with the Off-Grid Energy Access Fund (OGEF) to increase access to solar products in Togo, including solar-powered irrigation systems.¹⁰⁷ This continued reliance on corporate debt financing highlights the growing need for working capital as these companies scale their operations and expand their product offerings.

Previously reliant primarily on equity financing, agricultural off-grid appliance companies are also increasingly exploring debt options. SunCulture's \$12 million USD syndicated debt facility, led by Mirova SunFunder's Solar Energy transformation (SET) fund and Triodos Investment Management, allowed it to finance inventory and receivables for customer purchases of solar-powered irrigation products. This demonstrates the growing involvement of various stakeholders in supporting debt financing for PUE companies.¹⁰⁸ Additionally, InspiraFarms raised €5 million EUR from InfraCo to support its consumer financing rollout, allowing it to test innovative affordability models such as cooling-as-a-service.^{109, 110} These examples illustrate the growing diversification of debt financing options available to PUE companies.

DEMAND AGGREGATION FOR RENEWABLE ENERGY (DART) PROGRAM^{111, 112, 113}

Economies of scale present a major challenge in the distributed renewable energy (DRE) market as well as in the off-grid appliance market segment. Site development is time-intensive and often needs to be tailored to local conditions, which limits the scale potential that could drive capital costs down. Identifying an optimal location for a small mini-grid or identifying potential customers for appliances requires considerable resources, particularly as the factors influencing these decisions are highly specific to local contexts.

Recognizing this, the Global Energy Alliance for People and Planet (GEAPP), All On, and Odyssey launched the Demand Aggregation for Renewable Technology (DART) Program in Nigeria in 2021. The DART program operates as a central source to aggregate demand for individual component procurement and logistics. Further, the program provides optional equipment financing in the form of debt. The program is open to small-scale solar for income generation, and the financing facility offers indicative terms of a 24-month tenor with a 6-month moratorium on interest rate and premium payments, with options to finance in both US dollars (9%) and Naira (13%). The program was launched in 2022 at \$10 million USD and was scaled up to at least \$25 million USD by the end of 2023 based on interest from companies in the sector.

Bulk procurement programs have also been used in other countries, for example in India under Energy Efficiency Services Limited (EESL). The company was set up in 2009 as a super energy service company (ESCO) with the goal of increasing energy efficiency through bulk procurement and the associated cost reductions for technologies including electric mobility, solar water pumps, LED lighting, and others. Such programs can effectively leverage public or other concessional capital to unlock demand for new technologies.^{114, 115, 116} ■



Simusolar water pump customer
Photo Credit: Simusolar

Companies demonstrating strong growth potential can explore sustainability bonds as a financing avenue. For instance, BURN Manufacturing, which targets low-income households (although not off-grid customers directly), successfully issued a 1.5 billion KES green bond in 2023. The proceeds supported the growth of its production of clean cooking solutions such as electric pressure cookers, including the expansion of its facilities in Kenya and the construction of a new facility in Nigeria.¹¹⁷

For companies that are much earlier in their growth journeys, blended finance is unlocking small-ticket debt investment. In light of the concentration in investment seen in the sector, and therefore the growing demand for smaller debt financing solutions, Charm Impact was launched in 2018 to provide small-ticket debt (under £350,000 GBP) through crowdfunding, enabled by blended finance. An example includes loans to Modern Farming Technologies (MFT) in Malawi for solar irrigation systems (2021).¹¹⁸

Some companies have secured concessional debt: for example, Agsol's zero-interest loan from the JLL Foundation.¹¹⁹ While less prevalent, such options can be crucial for early-stage companies or those operating in challenging environments.

DEBT SECURITIZATION

Debt securitization offers a unique financing option for larger off-grid appliance companies with substantial customer bases and predictable cash flows. This process involves pooling loan receivables from numerous customers and selling them as bonds to investors. The resulting cash flow from these bonds is used to repay the original debt, while investors earn a return on their investment.

Large off-grid solar companies have managed to implement large debt securitization transactions in the countries where they work. In 2023, SunKing closed a \$130 USD million securitization of customer payments alongside a \$20 USD million working capital facility from Stanbic Bank Kenya and BII.¹²⁰ The securitization involved investors such as Stanbic Bank Kenya, BII, ABSA Kenya, Norfund, FMO, and the Trade and Development Bank. These investors contributed to a special purpose vehicle (SPV) called SunKing Financing Ltd that will acquire the company's receivables.^{121, 122} Similar arrangements were established by d.light in Tanzania (\$30 million USD facility) and Nigeria (10 billion Naira), funded by

TBD Group and Chapel Hill Denham, respectively. d.light also recently also closed a \$176 million USD deal covering Kenya, Tanzania, and Uganda.^{123, 124, 125}

While still in its early stages within the off-grid appliance market, debt securitization has the potential to become a valuable financing tool for established companies with robust customer bases. Benefits include access to large pools of capital, improved liquidity, and potential for credit rate enhancement. Downsides may include exposure to interest rate fluctuations and potential risk if the underlying assets perform poorly.

As the market matures and companies gain experience with this instrument, we can expect to see further innovation and wider adoption of debt securitization in the off-grid space. This model, however, is most relevant for markets where PAYGo solar is typical rather than markets where forms of consumer finance such as MFIs are more common.

PROJECT STRUCTURES

In recent years, project structures have emerged as a novel financing mechanism for energy systems. These involve establishing an SPV to manage and finance a specific project, such as the deployment of solar irrigation systems. Investors can then participate in the project through the SPV, enabling the pooling of resources and mitigating risks.

One example of this approach is InfraCo Africa's investment in Bonergie Irrigation, an SPV established in Senegal to install solar-powered irrigation systems. This project aims to reduce dependence on rain-fed agriculture and improve productivity for farmers, installing up to 2,000 solar-powered irrigation systems.^{126, 127}

Project structures offer several advantages for financing appliance applications, including risk mitigation, mobilization of capital, and flexibility, as the structure can be tailored to the specific project. One of the biggest advantages, as with debt securitization, is removing the need for debt on balance sheets and the corresponding equity need to manage debt-to-equity ratios, as well as enabling companies to limit the working capital cycle while still offering end-user financing. While still evolving, project structures hold promise for unlocking additional financing options for the off-grid appliance market, particularly for large-scale agricultural applications.

CARBON FINANCE IN THE OFF-GRID APPLIANCE MARKET ¹²⁸

Solar appliance markets are often characterized by limited access and significant affordability hurdles for customers. To overcome these challenges, companies are increasingly exploring climate finance, including carbon markets, as an additional revenue and financing source. These markets are well established in the adjacent clean cooking markets.

For income-generating appliances in agriculture, several projects are under development in Africa and India to monetize carbon credits based on emissions reductions generated by displacing diesel- or petrol-powered pumps with solar-powered pumps. One such developer, Kenya’s SunCulture, raised \$2.6 million USD in financing from BII and Shell Foundation to design and finance a facility to capitalize on carbon credits. The credits are expected

to reduce the cost of irrigation systems by 25% to 40% and reach 9,000 farmers in Kenya.

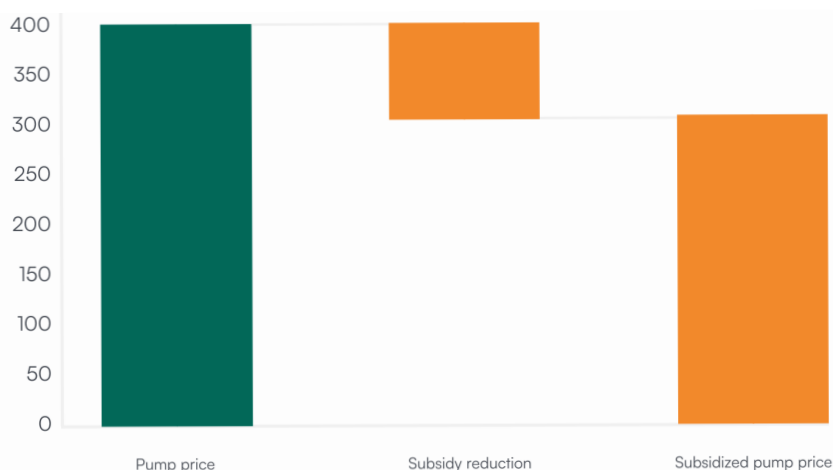
Despite the potential of the carbon market, some risks still remain. The carbon markets have experienced price volatility in recent years, particularly for clean cooking projects, where studies have raised concerns about the quantification of carbon benefits. Investors also perceive additional risk, particularly political risk, as countries across developing markets create frameworks to regulate carbon credits (acknowledging that Article 6 legislation^{xxvii} also presents new opportunities in the sector, allowing companies to sell into more international regulated markets).

Only well-resourced companies have successfully accessed carbon finance. The costs to develop carbon projects can be high compared to the initial benefits for companies. However, better access to information on climate finance solutions, as well as new methodologies that evaluate the full suite of benefits for off-grid appliances, including environmental and social impacts, could greatly increase companies’ reach and unlock the full potential of climate finance in accelerating access to valuable energy services. ■

xxvii Article 6 of the Paris Agreement Crediting Mechanism: <https://unfccc.int/process-and-meetings/the-paris-agreement/article-64-mechanism>

Figure 19: Carbon finance in the off-grid appliance market

ILLUSTRATIVE EXAMPLE OF IMPACT OF CARBON REVENUES ON SOLAR WATER PUMP COSTS (USD)



DEDICATED IMPACT FUNDS

The off-grid appliance market has attracted the attention of several dedicated funds and investors that recognize the sector’s potential for both financial returns and positive social impact. These institutions offer various financing options catering to different company sizes, technological focus areas, and

geographical locations, contributing to growth and innovation within the sector. Table 8 notes a few such funds. It is important to note that many (though not all, and not exclusively) of these funds are funded by public funding, foundations, or high-net-worth individuals, with more limited funding from commercial sources of capital.

Table 8: Examples of impact funds with mandates that may include off-grid appliances^{xxviii}

INVESTOR / FUND	INSTRUMENT	STAGE	EXCLUSIVELY ENERGY?	GEOGRAPHY
DOB Equity¹²⁹	Equity	Seed to Series A	No	Kenya, Tanzania, Uganda
Cygnum Capital / Off-Grid Energy Fund (OGEF)	Debt	Various	Yes	Africa
Mirova / Gigaton Fund¹³⁰	Debt	Various	Yes	Africa, Asia, Latin America, Middle East
GEAPP / Productive Use Appliance Finance Facility	Consumer financing, capacity building grants, procurement subsidies	Early	Yes	Democratic Republic of Congo, Ethiopia, Kenya, Nigeria, Sierra Leone, Uganda
Acumen / Pioneer Energy Investment Initiative: Powering Livelihoods Using Solar (PEII+)¹³¹	Equity	Various	Yes	East Africa, West Africa, India
Charm Impact and CLASP / Supporting Early-Stage Local Entrepreneurs (SESLE) Program¹³²	Guarantees	Various	Yes	Kenya, Nigeria, Rwanda

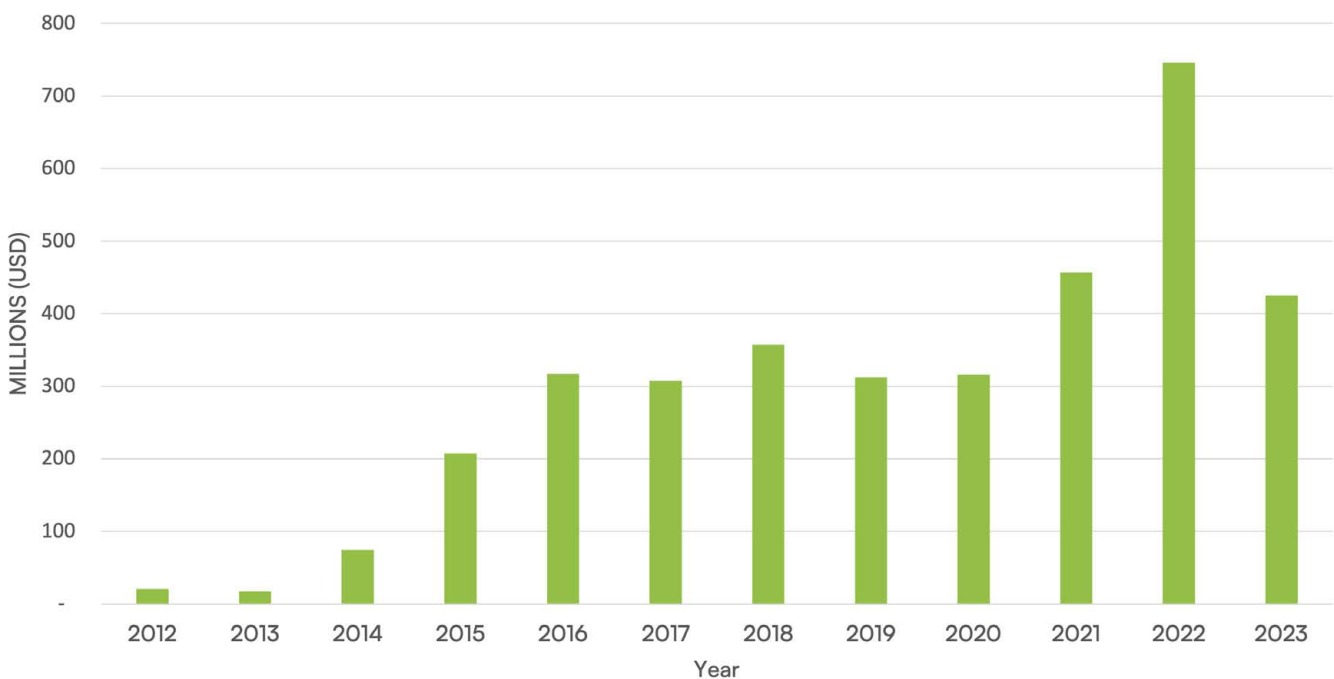
xxviii This table is not exhaustive and provides only a snapshot of some dedicated funds operating in the off-grid appliance market.

Although dedicated funds for off-grid appliances exist, they currently only meet a tiny fraction of the overall need. As the sector has developed, funding has been increasingly concentrated in a small number of companies. In the off-grid solar sector, for example, seven companies had raised 72% of all investment as of 2022.¹³³ Many stakeholders in this study that are not those top-funded companies noted that they find it difficult to scale their businesses due to a lack of funding, particularly equity investment, which is needed to raise further debt funding and enable expansion. And though the off-grid solar sector raised a record \$746 million USD,¹³⁴ only a portion of that funding will flow specifically to

appliances. These investments are far short of the billions required to reach the market potential for off-grid appliances between 2024 and 2030.

The MTR 2022 report¹³⁵ states that large companies absorb the majority of investments, but even if they were to grow tenfold, it would still take 19 years to achieve universal energy access. The off-grid appliance sector has seen greater funding thanks to increasing investment in agricultural and climate impact, but to reach its potential, companies will either need to demonstrate a clear path to scale to satisfy investors' demand for returns or find an alternative funding approach.

Figure 20: Tracking private-sector investment into the off-grid sector²¹⁹



3.6 Business model trends

The business model landscape for off-grid appliances is diverse and evolving, with innovations occurring along each segment of the value chain. The off-grid appliance sector is characterized by a multitude of business models, reflecting its diverse range of technologies, end users, and operating environments. The sector, building on the broader off-grid solar sector, is unique in its focus on underserved communities. This presents challenges of affordability, consumer awareness, and availability.

By 2019, there were dozens of manufacturers of high-quality off-grid appliances, with business models to deliver those appliances becoming increasingly specialized.¹³⁶ The years since have witnessed a surge in innovative approaches aimed at

overcoming affordability constraints and expanding access to clean energy solutions.





















Given the array of market conditions across countries and for different end users, as well as the range of technologies available, there is a high level of complexity in characterizing business models. Nevertheless, we can map companies across a typical value chain diagram. As Figure 21 shows, different archetypes of businesses that now operate in the sector may be involved in different areas of the value chain for off-grid appliances.

There is no one right business model; rather, it is important that the chosen business model is managed appropriately. Each business model has its own strength and weaknesses. For example, the capital need for vertically integrated business models



Person holding milled grain

Figure 21: Business types operating across the off-grid appliance value chain

Company Type	 Design & Manufacture	 Distribution, Sales & Marketing	 Consumer Finance	 After-sales Support
Off-grid appliance innovators Specialist product developers, often focused on one product category in particular.				
International appliance companies Larger, multinational firms that sell and distribute a range of appliances which may include solar appliances.				
Off-grid solar companies Firms specializing in the production or distribution of off-grid solar products, which may power solar appliances.				
Local distributors Local distribution companies or retail shops that are technology agnostic.				
Mini-grid operators Operators of mini-grids may sell PURE appliances to their customers to increase electricity demand.				
Agricultural specialists Agriculture-focused organizations that may provide farmer inputs, aggregate produce, and/or distribute solar appliances				

Key: Green indicates the segment of the value chain where the business type often works. Blue indicates where the business type may also work, though less frequently.

is very high, which often requires regular capital raises to continue fueling company growth. Local distributors may have the advantage of a lower cost structure to reach end users in underserved areas, but they may be more constrained in their capacity to buy inventory, or by exclusivity agreements with manufacturers. Ultimately, the appropriate business model depends on the local context and the end consumers served by the company.

This section describes several recent trends in the evolution of business models in the off-grid appliance sector mapped against the sections of the value chain for off-grid appliances.

DESIGN AND PRODUCTION

There is a growing level of interest in local assembly and manufacturing of off-grid appliances. Today, many countries in the key off-grid appliance markets in sub-Saharan Africa import the majority of their appliances from global manufacturing hubs, primarily China. Localization of supply chains holds the potential to boost tax revenues, increase job opportunities, improve quality control for local suppliers, and reduce appliances' carbon footprint.¹³⁷

Localization may require overcoming significant challenges, however. These can include difficulty accessing labor or know-how to set up facilities in areas with underdeveloped manufacturing sectors, small local market sizes that make it difficult to achieve economies of scale, limited access to finance, and higher input costs.

The high cost of importing off-grid appliances and the potential benefits of localization have created a commercial opportunity for more generic, non-specialized appliances. Generic appliances use older generations of technologies and have limited functions while maintaining basic features. These products are typically less energy efficient but more affordable than branded off-grid appliances.¹³⁸ In Nigeria, for example, some off-grid appliance companies, such as Community Energy Social

Enterprise Limited (CESEL),¹³⁹ have deployed locally manufactured oil palm pressers and millers for agriculture-related activities in agrarian communities. Pet-Feb, a Nigerian renewable energy company, is working with informal assemblers and technicians to assemble solar DC fans.

Manufacturing maturity varies significantly across countries. For refrigerators, for example, Indian companies are increasingly sourcing components for off-grid solar refrigeration locally and are beginning to manufacture DC compressors in-country. By contrast, Kenya lacks local manufacturing, leaving it largely dependent on importing fully fabricated units.¹⁴⁰

SALES AND DISTRIBUTION

Ensuring the effective and widespread sale and distribution of off-grid appliances is fundamental to providing access to energy services. This section delves into the evolving landscape of distribution channels and explores innovative approaches companies are adopting to reach diverse customer segments across remote and underserved communities. We examine the role of traditional channels like direct sales and retail networks, while also highlighting the growing significance of digital platforms and alternative distribution models tailored to the unique needs of the off-grid market.

For off-grid household and small income-generating appliances, there is a wide range of existing distribution channels. One is longstanding retail outlets that include electronics shops, specialized appliance shops, and petrol stations. Another is agent networks that sell directly to households, allowing companies to interact directly with customers for sales and after-sales support.¹⁴¹ These are commonly used for appliances bundled with off-grid solar solutions that are sold by off-grid solar companies.¹⁴²

Given the breadth of the market, ascertaining which type of business model is used to convert sales across different countries is challenging. Limited data is available to indicate where exactly appliances are sold.

GLOBAL DISTRIBUTORS COLLECTIVE^{143, 144}

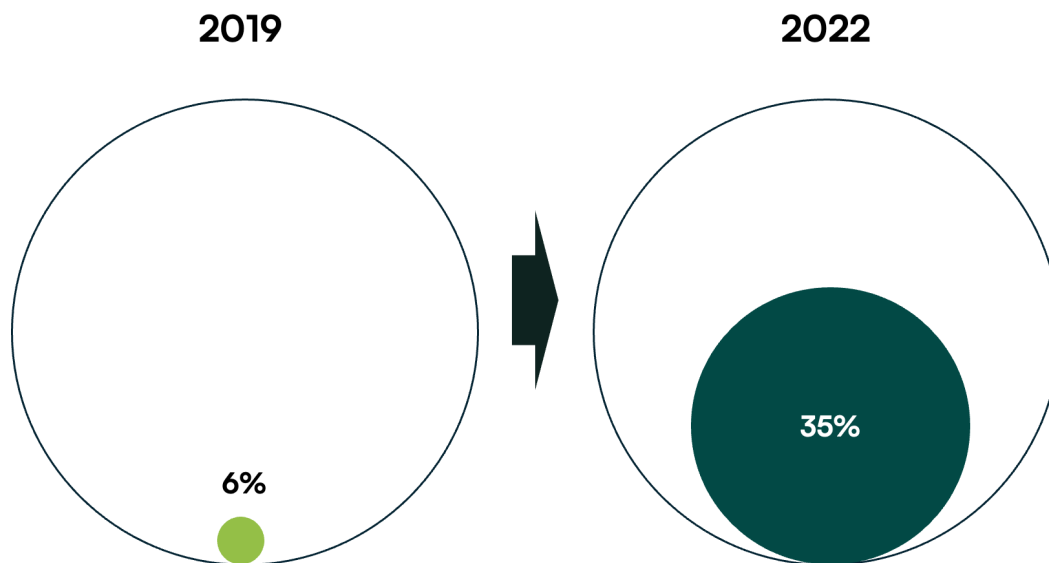
The Global Distributors Collective (GDC) consists of over 200 last-mile distributors (LMDs) from across more than 60 countries that sell products beneficial

for end-customers. The GDC's members have reached over 40 million customers with products that include income-generating appliances, off-grid appliances and lights, improved cooking solutions, and agricultural inputs, among others.

Surveying 132 of its members for the *Last Mile Distribution: State of the Sector 2022* report, the organization found that between 2019 and 2022, the proportion of those surveyed whose portfolio included income-generating appliances increased from 6% to 35%. (This category covers appliances that generate commercial income as well as those that result in cost savings in the home.) Of these, the most commonly sold appliance was the solar water pump (26% of members), while others included refrigerators, solar millers, egg incubators, solar hair clippers, and solar drip irrigation.

Growing involvement with these appliances has also been demonstrated by surveys showing that 21% of GDC members are interested in selling them. ■

Figure 22: Proportion of GDD members selling income-generating appliances in 2019 and 2022^{145, 146}



As the sector has evolved, more companies are specializing in the market, resulting in more business-to-business-to-consumer (B2B2C) models. Though direct B2C sales were necessary when product awareness was relatively low, many companies have opted to sell B2B2C in order to scale. This allows them to avoid last-mile distribution, which can be costly for companies with a small product range.

For example, this trend has been observed among large off-grid solar companies in India that may have hundreds of B2B partners. It has also been employed by agricultural appliance companies like Uganda's Tulima Solar, which has a blended approach of selling B2C as well as through a network of companies selling directly to customers and through cooperative organizations that reach a large number of end users.

Some companies seek partnerships with large international corporations. Nigeria's Koolboks, for example, has partnered with Orange, which will market and distribute Koolboks' refrigeration and freezer solutions through its Orange Energies platform in 12 African countries, starting in the Democratic Republic of Congo. Orange will also make the product available on its PAYGo platform, Orange Smart Energies.¹⁴⁷ As of late 2023, Koolboks was launching pilots with Coca Cola and Danone to test its product under a cooling-as-a-service model and in retail outlets, respectively.^{148, 149}

Service-based models have emerged in an attempt to solve the affordability gap for clients. For large appliances that can serve multiple end users, some companies are adopting a service-based model, avoiding the need for customers to pay full price for an appliance upfront.

For example, while some companies are focusing on developing more affordable solar-powered pumps for smaller-scale farmers, Oorja Development Solutions is rolling out a water-as-a-service model where smallholder farmers surrounding a central solar water pump pay an initial membership fee, then pay for water on a per-liter basis, preventing the need to purchase their own pumps.¹⁵⁰ ColdHubs in Nigeria sets up its solar-powered cold storage hubs in central locations where farmers or traders can store their produce. End users pay on a pay-as-you-store basis, averting the need to individually purchase cold storage units.¹⁵¹

However, while this model may help farmers overcome the affordability gap, it creates a working capital challenge for companies needing to cover high capital costs for their equipment. Further, many companies are still refining their unit economics at a system level, which includes building out systems and developing capacity so that end users maximize usage of the assets.

Market linkages are critical to maximize the benefits for large-scale agricultural off-grid appliance users. Several companies are operating within agricultural value chains to improve the value proposition for their customers. Some companies discovered that product development and distribution were not sufficient to boost customers' incomes, leading them to more directly enter the agricultural value chains where these customers operate.

For example, India's Raheja Solar sells affordable, easily assembled, locally manufactured solar dryers to rural farmers. It also buys dried produce from the farmers to sell to end consumers.¹⁵² In Kenya, Adili Solar Hubs initially implemented a project to install solar-powered cold storage for fish preservation but has since moved into procuring and marketing fish on behalf of the fishers, taking an active role in the fish value chain.¹⁵³

In recent years, online retail platforms like Amazon, Jumia, and Konga have emerged as a way to purchase off-grid appliances. Although they make it easier for customers to identify and understand potential products, to date they have been most heavily used in urban centers where customers are more familiar with them. The use of these platforms is currently limited by consumers' preference to see the appliance in person and speak to a retailer directly to ensure that it meets their needs.¹⁵⁴

CONSUMER FINANCING

Affordability is one of the most significant hurdles hindering widespread adoption of off-grid appliances. In the absence of robust and accessible financing options, even the most life-changing appliances remain out of reach for many low-income households. This section explores the evolving landscape of consumer finance solutions in the off-grid appliance sector, highlighting innovative approaches that are bridging the affordability gap and expanding access to clean energy.

The 2019 iteration of the State of the Off-Grid Appliance Market report noted that growth in mobile money use and microfinance institutions expanded consumer financing options with early PAYGo models and consumer finance via MFIs. Today there are more pricing options available to consumers across the market than ever before (e.g., pay-per-day, pay-per-use, and pay-per-amp¹⁵⁵). Companies can charge customers in a variety of ways, with permutations ranging from variable payment duration to the ability to prevent customers from using products if they fall behind on payments.

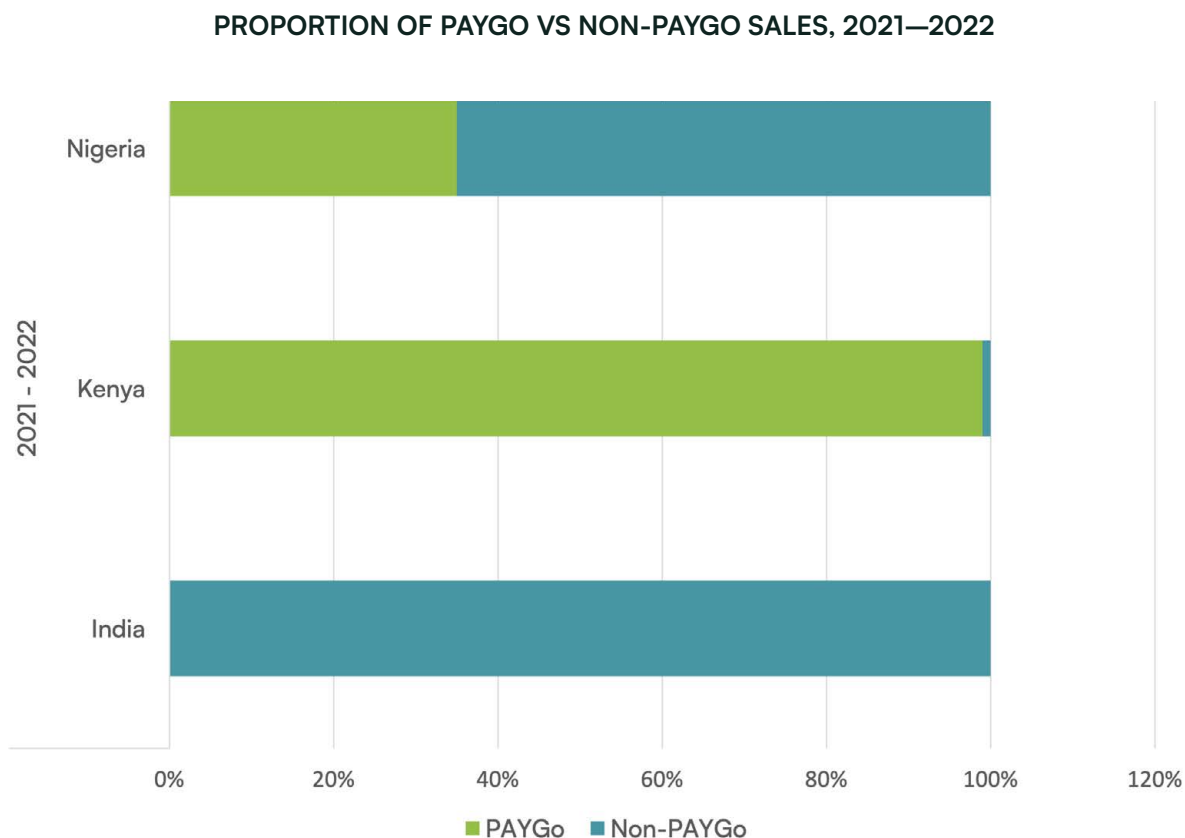
PAYGO

Cash sales are beneficial for company cash flow, but many end consumers face affordability challenges,

limiting companies seeking cash payments to higher-income customers. PAYGo unlocks a broader customer base by allowing customers to pay for access to an appliance over time, eventually gaining full ownership. PAYGo models have risen to prominence in some markets in sub-Saharan Africa, particularly East Africa and Kenya, offering a crucial pathway to affordability for many low-income households (Figure 23). PAYGo differs from other forms of consumer finance in that it is provided directly by the company selling the product, and in its ability to shut appliances off remotely in the case of nonpayment.

In Nigeria, PAYGo is rapidly becoming a key consumer financing model for off-grid appliances. An increasing number of off-grid appliances, including

Figure 23: Country dominance of PAYGo versus non-PAYGo consumer financing models for all solar energy kits and appliances as tracked in the biannual GOGLA sales data collection processⁱ



ⁱ GOGLA, collected as part of its biannual sales data gathering

household appliances, water pumps, refrigerators, and freezers are integrating PAYGo in their design and financing models. As consumer awareness of the model grows, Nigerians increasingly embrace it as a viable alternative to cash payments, particularly given the rising price of fuel (i.e., gasoline and diesel) in the country. Despite Nigeria's significant government subsidies for diesel and gasoline, which have historically made these fuels more economically attractive, the PAYGo model offers installment payments that are now competitive with the cost of diesel. This financial parity is facilitating the transition to solar-powered appliances and making them a more viable option for consumers.

Government efforts to increase rural mobile connectivity via initiatives such as the Nigeria National Information and Communication Technology Infrastructure Backbone (NICTIB) Project are also boosting PAYGo's popularity.¹⁵⁶ Adoption is higher in peri-urban and rural areas, particularly in the western part of the country, which has a higher presence of suppliers and relatively high income levels. In the north, adoption is also relatively strong due to development programs focused on poorer, rural populations. PAYGo is less common in the south, despite relatively high income levels, because there are fewer companies offering this model.¹⁵⁷

Widespread adoption of PAYGo presents challenges for companies and consumers, however. The model's sustainability depends on managing credit risk and ensuring efficient collections. As the sector has evolved in recent years, some companies have begun to outsource consumer finance tasks to entities such as specialized collection agencies. For example, Kenya's Glichery collaborates with d.light, SunCulture, and Davis & Shirliff.¹⁵⁸

For PAYGo to be truly sustainable, it must be financially beneficial for both companies and customers. Consequently, companies within the sector are developing more sophisticated underwriting techniques and more streamlined debt collection processes.

Sales and consumer finance of off-grid appliance also expose customers to risk. Examples include the purchase of low-quality products that quickly become obsolete, the potential of becoming overburdened by debt, and the ongoing collection of customer data. Additionally, companies may remotely

deactivate devices in case of non-payment, which can result in lost revenue and jeopardized livelihoods when affecting income-generating appliances.

To protect appliance users from these risks, GOGLA developed the Consumer Protection Code, a set of principles and an assessment framework that enables companies to measure and track positive impacts. To date, over 50 companies have committed to the Consumer Protection Code, while over 20 investors and other stakeholders in the ecosystem have endorsed it.¹⁵⁹

OTHER FINANCING MECHANISMS

PAYGo is much less common in South Asia. In countries like India, products are often financed by traditional financial institutions. While India has a native PAYGo technology developer, KPAY, there has not been any substantial update of PAYGo financing in the country.

In India, MFIs play a major role as a channel partner and financier for high-quality solar off-grid solar systems in rural areas, allowing customers to pay overtime with equated monthly installments (EMIs).¹⁶⁰ This also applies for income-generating products, as in the case of Devidayal Solar's initial 10 million INR (approximately \$130,000 USD) deal with Ashv Finance to enable financing for solar refrigerators in Rajasthan, Uttar Pradesh, and Assam.^{161, 162} The company has also developed PAYGo-enabled solar refrigerators, though these will likely be sold through its partners in Africa in the short term, given the predominance of PAYGo across some countries there.^{163, 164}

Though finance through existing financial institutions may be more common in South Asia than in sub-Saharan Africa, several examples exist in the latter, particularly for larger income-generating appliances. Many local financial institutions consider smallholder farmers very high risk, especially for new technologies.¹⁶⁵ Some organizations have successfully set up facilities, however. For example, water solutions provider Davis & Shirliff developed a partnership to finance solar water pump assets with National Bank of Kenya.¹⁶⁶ In Nigeria, Kooboks partnered with LAPO Microfinance to provide micro loans for the company's cold storage products.¹⁶⁷ MFI reach may be limited to certain states of regions within a country, however, excluding portions of the population.¹⁶⁸

Cooperatives and associations also play a role in financing equipment. Consumers leverage cooperative groups to finance off-grid appliances, particularly in rural areas and for larger and costlier appliances. These fundraising mechanisms are critical in remote areas, where there is often less access to microfinance and other financial institutions. Unlike models like PAYGo, however, they are restricted to areas where cooperatives already exist.

Cooperatives can support access to appliances in different ways, including purchasing them themselves. Nigeria's Sosai Renewables, for example, works with rural women cooperatives under its Matan Arewan Sosai Initiative to purchase solar dryers that cooperative members use for drying and

preserving produce.¹⁶⁹ Another arrangement allows members to leverage the cooperative's monthly contributory scheme to raise funds to purchase off-grid appliances.

AFTER-SALE SUPPORT

Appliance companies working in agricultural value chains find it valuable to provide their customers with information that allows them to maximize the benefit of their asset. This requires additional resourcing.¹⁷⁰

In India, Ecozen provides market intelligence to its customers about the prices of produce at different points of the year via its post-harvest management team, helping end users maximize their profits.¹⁷¹



Ecozen employees in a cold storage unit in India

PROMETHEAN POWER

172, 173, 174

India produces vast quantities of milk every year, but the majority is not chilled or processed. Of 210 million metric tons of milk produced annually across 70 million dairy farms, only 75 million metric tons are processed. Only a portion of the processed milk is then chilled. Milk must travel long hours to reach larger collection centers, as villages are not often connected directly to dairy farms.

Promethean Power, a developer of thermal battery technology, has focused solely on this challenge since 2012. The company has scaled its milk chilling technology down so it can be used at the village level, reaching 1,000 liters for bulk milk chilling, which can serve 50 to 70 farmers. The company has deployed solar-powered systems in partnership with World Wildlife Fund, although most of its systems are grid-connected and not all are powered by solar.

To further increase usability, the company now aims to digitize systems and processes for its customers. This includes the development of a system called ProAMCsU to digitize the collections process, increase data collection on testing, increase visibility for producers on market rates, and enable users to understand system performance for preventive maintenance. The app, which can be used on any Android device, captures key data on milk quality on mobile devices.

Such technology platforms can ultimately increase usability at the farm level, increasing farmer earnings by improving quality and market knowledge while improving transparency and traceability for buyers. ■



Customer of Global LEAP Awards Off-grid Cold Chain Challenge finalist FreshBox milking his cow in Kenya.
Photo Credit: Efficiency for Access

After-sales support is critically important for income-generating appliances. Interruption of operations can result in lost revenue both for companies operating service-based models and for owner-operators of such appliances. If appliances used to store goods fail during times of heavy use, these losses can be significant. Therefore, effective maintenance, potentially using predictive capabilities, is of utmost importance. Companies must be equipped to provide support to assets across geographically dispersed areas, which can be time- and resource-intensive.

End-of-life management remains a challenge for companies, with various driving factors, including government e-waste regulations and policies, on the rise.¹⁷⁵ Finding avenues to reuse lithium-ion batteries is one potential solution. For example, Nigeria's Hinckley Recycling, a collector and recycler of e-waste across the country, has implemented pilots that produce and use second-life batteries for off-grid cold chain.¹⁷⁶ Other companies have

incorporated e-waste management into their business models; this is particularly true for off-grid solar companies that already have distribution networks that interact with existing customers.

Such companies reclaim damaged or end-of-life products, return them to their factories, reclaim reusable parts, and create a second-life product to sell back into the market.¹⁷⁷ One such company is SunKing, for which e-waste is a central component of its environmental risk management policies. The company aims to recycle, repair, and refurbish as much as possible to reduce e-waste.¹⁷⁸ This requires not just minimizing the creation of waste but also developing human resources to manage it, including creating recycling strategies and refurbishing end-of-life products, as well as those under warranty, and raising awareness of e-waste.

These processes may not exist in many portions of the market, especially where customers don't interact with field agents or other distribution points.



Solar panel installation
Photo Credit: Simusolar

3.7 Enabling environment

The pursuit of sustainable development and the fight against climate change have become intertwined global priorities. International agreements such as those reached at Conferences of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) highlight the urgency of finding solutions that address both environmental challenges and development goals. Solar-powered appliances can serve as a tool for achieving this dual mandate, particularly in developing countries. To achieve these benefits, a robust enabling environment is required.

The enabling environment has been highlighted consistently by industry actors as critical to unlocking growth in the off-grid solar market.^{179, 180} This chapter explores how government policies, regulations, fiscal policies, support programs, and quality standards impact the market growth and adoption of these critical technologies.

The global policy environment for off-grid appliances has witnessed incremental progress in recent years, encompassing various legal frameworks ranging from acts, regulations, and standards to national action plans and strategies, as the world strives to address the pressing issue of sustainable energy access while also achieving climate goals. By analyzing these developments, we aim to inform strategies that can unlock the full potential of off-grid appliances in driving climate-resilient development.

POLICIES, IMPLEMENTATION PLANS, AND SECTOR-SUPPORT PROGRAMS

Government policies, implementation plans, and support programs play a critical role in fostering the adoption of off-grid appliances and empowering end-consumers to access them. Well-crafted policies can create an enabling environment that lowers the upfront cost of off-grid appliances, encourages market growth and innovation, and simplifies import and regulatory processes. The policy landscape includes many layers, from country-level development plans to sectoral and cross-cutting policies and action plans.

Given their many uses, off-grid appliances are considered a key lever for achieving a variety of

goals in regard to climate change. Solar energy kits, for example, have been adopted widely as part of climate change mitigation and adaptation plans: As of 2022, 33 countries had included them in mitigation plans, while five countries had included them in adaptation plans. This is particularly true for kits that are sold together with small off-grid appliances like fans, televisions, and radios.¹⁸¹

Governments have also incorporated off-grid appliances into cross-cutting development plans such as their nationally determined contributions (NDCs). For example, Namibia submitted its updated NDC in January 2024 with provisions to transition fossil fuel-powered pumps to solar PV-powered electricity pumps, targeting 20,000 units by 2030. The country also plans to introduce more energy-efficient appliances into its market.¹⁸²

However, many countries charge taxes and duties on off-grid appliances, sending conflicting messages about their commitment to using them to achieve climate change and development goals.¹⁸³

Beyond cross-cutting policies and action plans, the active involvement of various government ministries and departments is crucial for the successful integration of off-grid solar solutions. Each of these ministries has goals which can be achieved by off-grid appliances. For example, ministries of energy play a critical role in improving access to clean and modern forms of energy, which can lead them to prioritize off-grid appliances. Ministries of finance are involved in the design of fiscal policies that incentivize investments into off-grid solar. Ministries of agriculture may have an interest in increasing productivity through solar water pumps or reducing spoilage with cold storage, while ministries of health may have an interest in the comfort and health benefits of space cooling and the preservation of medicine or vaccines. By working together, these government bodies can create a comprehensive policy framework that fosters a thriving market for off-grid appliances, empowers end-consumers, and unlocks the transformative potential of these technologies for sustainable development.

Cross-cutting development plans can play a substantial role in focusing efforts to make improvements in off-grid appliances. As development, global temperatures, and urbanization increase, so does the demand for cooling. If

that demand is not met sustainably, Sustainable Development Goals are at risk.¹⁸⁴ National cooling action plans (NCAPs) have emerged as a policy tool to prevent such a risk.

Kenya's NCAP was enacted in 2023 as mandatory.¹⁸⁵ It aims to enhance access to sustainable cooling for all Kenyans and increase ambition of efficiency standards for air conditioners and refrigerators, including planned revisions for minimum energy performance standards (MEPS) by 2025. Additionally, it aims to raise awareness on energy labels for cooling products through annual retail awareness seminars and other measures.¹⁸⁶ Though these policies may apply to on-grid appliances, they can be developed to aid both on- and off-grid populations.

For sector support programs to be maximally effective, governments must harmonize policies and programs and coordinate across agencies. As

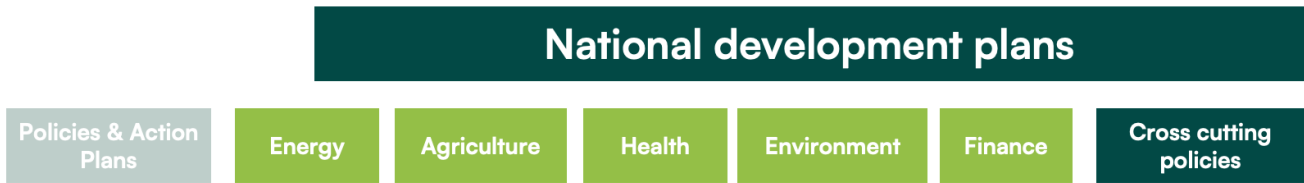
highlighted in Figure 24, off-grid appliances are relevant to several different ministries. Mobilizing programs often requires alignment and coordination between the ministry of finance and related ministries, for example to approve tax incentives or subsidy schemes.

Harmonizing programs across ministries can often increase efficiency. In India, for example, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) program led by the Department of Agriculture and Farmers Welfare subsidizes micro-irrigation systems for farmers, while the PM-KUSUM program within the Ministry of New and Renewable Energy subsidizes solar water pumping solutions. Consolidating programs could provide a more holistic package of support for potential beneficiaries to access the benefits of such products and make more effective use of government funding.^{187, 188}



Air conditioning units in Mumbai, India

Figure 24: Schematic of enabling environment components



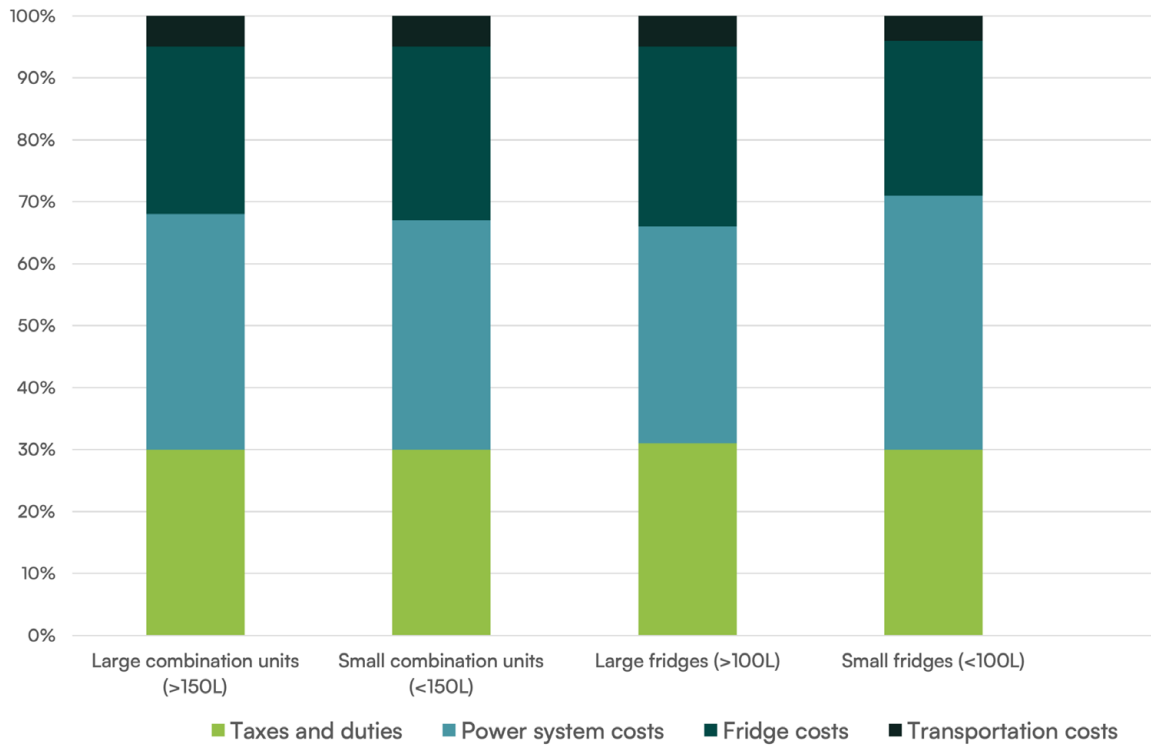
FISCAL POLICY

Fiscal policy can be a powerful tool for stimulating the growth of the off-grid appliance market globally. By strategically implementing a combination of tax breaks, subsidies, and targeted financial instruments, governments can address key barriers and create an enabling environment that attracts investment, fosters innovation, and ultimately makes these life-changing appliances more accessible to local communities.

One critical area for fiscal intervention is reducing the upfront cost of off-grid appliances. Import duty exemptions and reduced sales taxes on essential appliances like solar refrigerators, water pumps,

and cold rooms can make a significant difference. Reducing prices makes appliances more attractive to low-income households and small businesses, the primary drivers of demand in these regions. As of March 2022, several countries in sub-Saharan Africa—including Benin, Burkina Faso, Cameroon, Kenya, Liberia, Mali, Niger, Nigeria, and Serra Leone—had implemented some form of these incentives. However, the Off-Grid VAT and Duty Tracker developed by Power Africa with funding from USAID has found that in many of those countries, implementation challenges have hindered the effectiveness of these incentives.¹⁸⁹

Figure 25: Breakdown of cost components for refrigerators by refrigerator type¹⁹⁰



Fiscal policy can also encourage local manufacturing and assembly of off-grid appliances. Tax breaks for companies establishing production facilities within the target regions can create jobs, boost local economies, and ensure a more reliable supply chain. Additionally, governments can introduce investment tax credits for businesses that develop and manufacture innovative off-grid appliances tailored to specific regional needs.

The Indian government, for example, implemented successive incentive programs to stimulate its solar manufacturing industry, including allocating €570 million EUR under its Production Linked Incentive (PLI) scheme.¹⁹¹ A 2023 study concluded that this form of subsidy, in addition to access to credit, can support manufacturing in overcoming financial bottlenecks, thereby boosting localization of manufacturing.¹⁹²

Finally, strategically deployed subsidies can play a crucial role in bridging the affordability gap for low-income households. Results-based financing (RBF) has proven effective in increasing access and affordability for off-grid appliances in recent years. The instrument provides payments for pre-agreed results, also requiring verification for reaching end users. The subsidy can help companies reduce costs and expand their footprint or reduce retail prices. Much of this funding has been committed by development partners and governments to markets in East Africa and West Africa at \$260 million USD, or 58% of total funding, and \$116 million USD, or 26% of total funding, respectively.¹⁹³ Over time, more funding has targeted larger solar energy kits, capable of powering off-grid appliances, while more dedicated programs have targeted income-generating appliances like solar water pumps and refrigeration units.

STANDARDS

Consumer protection is vitally important for the off-grid appliance market. Purchasers of appliances can benefit from regulations that ensure the safety of use for appliances while also protecting customers against quality issues that can result in financial losses for customers with already limited financial resources. Low-quality products can also negatively

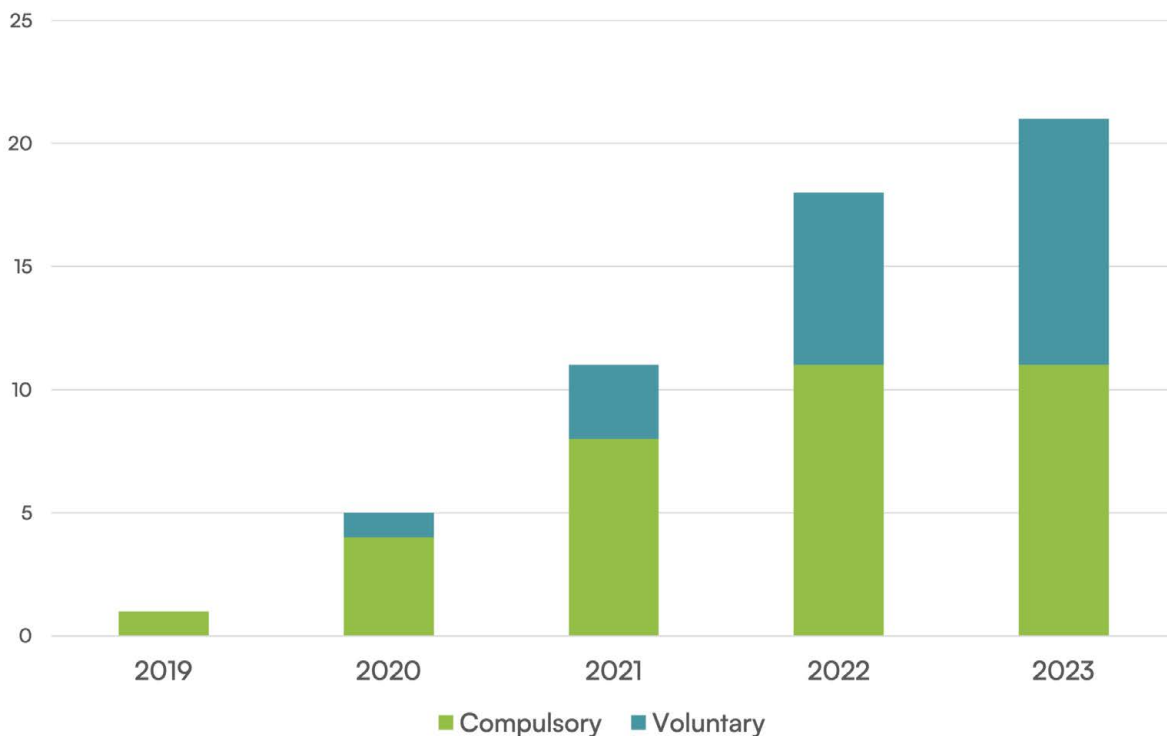
impact the environment, with products that are quickly spoiled generating e-waste or releasing harmful contaminants into the environment. Low-quality appliances can also impact the sustainability of off-grid appliance markets by shaking consumer confidence and creating reputational issues.

At the national level, countries are implementing standards to support the sustainable development of markets. It is common for countries to have safety standards to ensure that imported appliances do not present physical risks to their citizens, but standards can also cover quality, including durability, consumer protection, truth of advertising, and safety.^{xxix, 194}

One off-grid appliance category covered by quality standards is solar fans connected to solar energy kits. These are covered under the IEC quality standard for solar energy kits and pico-solar products (IEC TS 62257-9-8), which built on the Lighting Global Quality Standards developed by the World Bank Group. In total, 22 countries have adopted these standards as compulsory or mandatory; 11 have done so between the beginning of 2022 and the publication of this report. Since the beginning of 2023, Benin, Madagascar, Papua New Guinea, and the Economic Community of West African States (ECOWAS) have joined this group. See Figure 26 for an overview of adoption of this standard over time.

xxix IEC 62257-9-8 is the quality standard for solar energy kits and pico solar products (those with power ratings less than or equal to 350 watts). [Link](#).

Figure 26: Adoption of IEC quality standards (IEC 62257-9-8) as compulsory or voluntary for solar energy kits over time, cumulative governments ^{xxx}



^{xxx} Compulsory adoption implies that all products of the specified appliance type that enter a market must meet the standard or face penalties for non-compliance. Voluntary adoption implies that companies are strongly encouraged to meet the standards for the products and is often a precursor to compulsory adoption.

Test methods and standards are currently under development for solar refrigeration. There are no international standards for solar refrigerators, though there are standards for AC-powered refrigerators. This lack of standardization for off-grid appliances results in wide variation in quality and performance.¹⁹⁵

In response to initial government interest for such standards, VeraSol and market development programs such as the Global LEAP^{xxxi} Awards have developed initial testing methods that standardize testing for performance and quality for solar refrigeration.¹⁹⁶

^{xxxi} An international competition that identifies and promotes the world’s best, most energy-efficient appliances and equipment intended for use in energy-constrained settings. For more information, see <https://efficiencyforaccess.org/program/global-leap-awards/>

The IEC Technical Committee (TC) 59, which develops standards for household refrigeration products, has also¹⁹⁷ created a test standard for refrigerators that can operate on weak and off-grid power sources. Separately, United for Efficiency (U4E), a global initiative led by the United Nations Environment Programme (UNEP), has developed “Model Quality and Performance Guidelines for Off-Grid Refrigerating Appliances,” which provides voluntary guidance for stakeholders on energy efficiency and quality assurance for the use of refrigerants and foam-blowing agents.¹⁹⁸

The guidelines cover residential and small commercial applications, but not walk-in cold rooms (WICR), with the aim of supporting the growth of climate-sensitive, energy-efficient appliances without exacerbating existing access and affordability challenges.

As the off-grid appliance sector grows, standards will keep evolving to support its sustainable development, as seen in the weak-grid appliance market. For solar water pumps, there is already an IEC standard in place, but it does not currently address the smaller solar water pumps now being rolled out for smallholder and rural populations in developing markets. In response, efforts are underway to revise the IEC solar water pumping standard.¹⁹⁹ For WICRs, many of the individual components used are likely covered under existing standards, but a comprehensive standard covering all solar WICRs is likely far from being developed. This is because companies and development partners are still testing use cases, which is necessary to determine the configurations relevant for regulation. However, in December 2023 the International Institute for Refrigeration (IIR) and Efficiency for Access released a technical guide to support practitioners looking to design or operate WICRs in off- or weak-grid settings.²⁰⁰

These evolving standards build on other codes in adjacent markets that benefit weak- and on-grid settings. One example is IEC 60335-2-15, which was published in February 2020. It specified the

safety requirements and test methods for household and similar electrical appliances for heating liquids applicable to electric pressure cookers (EPCs), which are increasingly encouraged as a method to boost household electricity demand and improve access to clean cooking solutions.²⁰¹ IEC 60335 is a series of safety standards covering various appliances, including refrigeration, pumps, and fans, offering a useful starting point for policymakers to promote safety for consumers in both on- and off-grid settings.

The uptake of off-grid appliance policies is a positive development for the sector, but there is room to improve implementation. As a first step, the adoption of testing methods and broader sector policies can support policymakers. Upon adoption, monitoring and enforcing policies must be well-funded and trained to ensure effective implementation. Areas of improvement include the capacity of local standards authorities to enforce standards, the streamlining of standards and policies across jurisdictions, consistent application of policies and standards within countries, and thoughtful connections between standards, fiscal policy, and other policies that impact the off-grid appliance market.²⁰²



Efficiency for Access panel at the COP26 Resilience Hub in Glasgow, Scotland, in 2021

Photo Credit: Efficiency for Access



Solar panel user in India

RECOMMENDATIONS

WHAT IS NEEDED TO ACCELERATE THE GROWTH OF THE OFF-GRID SOLAR APPLIANCE MARKET?

Efficient solar-powered appliances offer scalable solutions to address sustainable development and climate impacts, reducing demand on grids, lowering greenhouse gas emissions, and building community resilience. Ensuring equitable access to energy services and affordable, efficient appliances is crucial.

The off-grid appliance market can thrive with coherent policies, substantial capital investment, and innovative business models. Strategic actions and cross-sector collaboration are essential to bridge the energy service gap and ensure that no one is left behind.

The following section outlines the necessary steps to achieve this growth and realize the opportunities ahead.

GOVERNMENTS: SUPPORT AN ENABLING ENVIRONMENT THROUGH INTEGRATION AND HARMONIZATION OF POLICIES, QUALITY ASSURANCE, AND CONSUMER AWARENESS

Governments play a pivotal role in fostering the widespread adoption of off-grid solar appliances across sectors such as agriculture, finance, education, health, and humanitarian efforts. The increased recognition of these appliances' utility in improving developmental outcomes such as mechanized agriculture (through solar-powered irrigation) and reduced food loss (through solar refrigeration) underscores the need for a supportive policy environment. However, challenges such as limited consumer awareness and a lack of coordination among stakeholders often hinder implementation of these technologies.

To address these challenges and close the affordability gap, we recommend the following:

DEVELOP INTEGRATED POLICIES AND COORDINATE EFFORTS ACROSS MINISTRIES.

- Establish cross-ministry task forces to streamline policies and regulations that encourage adoption

of the efficient solar appliances critical for fueling economies and improving livelihoods. For example, effective reduction of food loss and waste necessitates the sustainable management of the cold chain, which requires collaboration between ministries of agriculture, trade, environment, and health. This coordination not only enhances the efficiency and sustainability of the cold chain but can also contribute to meeting several Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 12 (Responsible Consumption and Production). However, these initiatives often operate in silos, focusing on specific stages or technologies. As a result, disjointed efforts lack coordination and synergy within the cold chain, reducing their effectiveness.²⁰³

- Engage in existing frameworks like GOGLA's Community of Champions, which aims to facilitate high-level interaction and collaboration between governments, the private sector, and development partners.
- Harmonize policies to unlock capital flows and maximize the impact of public funding in countries with existing development programs. Large bulk procurement programs tied to integrating solar appliances into relevant government programs such as electrification and agricultural programs could help address affordability issues.
- Develop comprehensive frameworks to support private-sector growth and facilitate public—private partnerships across sectors in countries without existing policies. An example of this is the National Cooling Action Plan for Kenya, which is designed to meet the country's growing cooling demand while minimizing climate and environmental impacts (see Case Study 10).

LAUNCH CONSUMER AWARENESS CAMPAIGNS

In partnership with experts, governments can promote energy-efficient solar appliances, highlighting their

long-term cost savings, environmental benefits, and ability to address gender and disability disparities.

These campaigns should be designed to educate consumers about the advantages of solar appliances and encourage their adoption. For instance, food safety is a pressing public health challenge. Governments could contribute to addressing this challenge by increasing consumer awareness of the dangers of eating poorly handled meat and fish, which could drive demand for off-grid refrigeration and better cold chains.

One successful example is a consumer awareness campaign in Ethiopia that aimed to increase food safety awareness among women. The campaign encouraged women to choose safe, intact tomatoes at markets and prepare them safely at home. This resulted in increased recall of safe food purchasing and preparation information, safer buying behavior, and a greater intent to buy intact tomatoes. Similarly, campaigns promoting the benefits of solar appliances can lead to increased adoption and

improved public health outcomes.²⁰⁴

PRIORITIZE QUALITY ASSURANCE AND CONSUMER PROTECTION

Maintaining high-quality standards is essential for consumer confidence and market sustainability. Governments can play a crucial role in ensuring that solar appliances meet rigorous quality standards, protecting consumers from substandard products and promoting healthy market growth. To achieve this, they can:

- Enforce rigorous quality standards to build consumer trust. One example of successful quality assurance measures is the adoption of IEC quality standards for solar energy kits by 22 countries in Africa and Asia. These standards ensure the safety and quality of solar appliances, giving consumers confidence in the products they purchase. Regional harmonization of these standards makes it easier for manufacturers to comply with regulations at scale, reducing costs and barriers to entry.

CASE STUDY 10

NATIONAL COOLING ACTION PLAN FOR KENYA

Kenya's National Cooling Action Plan (NCAP, 2023–2027)²²⁰ includes strategies such as accelerating market transition by promoting the adoption of high-efficiency cooling appliances and equipment, encouraging the use of refrigerants with low global warming potential, and enhancing the resilience of the agricultural value chain through improved access to agricultural cold chains. The plan recognizes the need for both on-grid and off-grid cooling solutions and acknowledges the critical role that solar appliances can play. Off-grid refrigerators, for example, can be powered by a broader range

of power sources, including direct current sources like batteries and solar PV arrays. This recognition is particularly important as Kenya's integrated electrification plan identifies 1.96 million households that will be best served by off-grid standalone solar systems.

To be effective, the plan requires coordination among various government stakeholders, including the Ministry of Environment, Climate Change and Forestry; Ministry of Energy; Ministry of Agriculture; Ministry of Industry, Trade and Investment; and National Treasury and Planning. The NCAP outlines a timeline and assigns specific responsibilities to these agencies. For example, the Ministry of Environment, Climate Change and Forestry is tasked with raising efficiency standards for air conditioners and refrigerators, while the Ministry of Industry, Trade and Investment is responsible for creating an enabling environment for the cold chain market. The National Treasury and Planning is expected to provide fiscal benefits for cold storage systems and implement favorable policies for high-efficiency products. ■

- Protect local markets from the dumping of old and inefficient technologies by implementing policies restricting the import of substandard products. This could include setting minimum energy performance standards (MEPS), banning the import of certain technologies, and imposing tariffs on low-quality imports.
- Promote the right to repair and interoperability to ensure consumers have access to affordable repair services and can use their appliances with a range of compatible components. This approach not only extends the lifespan of solar appliances but also reduces e-waste and promotes a circular economy.
- Prioritize end-of-life management for solar appliances, ensuring that they are disposed of safely and responsibly. This includes implementing policies that encourage recycling and proper disposal of appliances, as well as providing incentives for manufacturers to design products with end-of-life considerations in mind. Some guidelines for refrigerators and walk-in cold rooms are provided in the Efficiency for Access note for policymakers.²⁰⁵
- Ensure consumers have access to efficient appliances from the onset by providing incentives for the adoption of high-efficiency appliances, such as tax credits or rebates, or setting ambitious efficiency targets for the off-grid appliances. This strategy helps leapfrog outdated technologies and promotes products that benefit both people and the planet.

SUPPORT LOCAL MANUFACTURE AND ASSEMBLY

Governments and relevant stakeholders need to strengthen the manufacturing sector for solar equipment to create thousands of skilled jobs in the off-grid solar appliance industry.

Among the countries focused on in this report, India has the most developed manufacturing sector for solar modules and solar appliances. Except for electronic components, all parts for solar appliance technologies are locally sourced within the nation. The Indian SWP sector is projected to support 5,500 manufacturing jobs by the end of 2030. These workers hold highly technical positions such as welders, CNC operators, and laser cutting operators.²⁰⁶

Kenya and Nigeria also have huge potential for the manufacturing of renewable energy products. For example, Kenya is on its way to achieving 100% renewable energy in its electricity sector. This will create massive local demand for renewable energy products. In addition, both Kenya and Nigeria have legislative frameworks for renewable energy and manufacturing.²⁰⁷ However, to attract investment in manufacturing, challenges such as political instability, infrastructure (especially energy for industrial uses), and a lack of local expertise need to be addressed.²⁰⁸

INVESTORS, DEVELOPMENT PARTNERS, AND FINANCIERS: DEPLOY SUBSTANTIAL AMOUNTS OF CAPITAL

Investors, donors, and financiers play a crucial role in increasing access to appliances suited for off-grid and weak-grid markets. Substantial deployments of capital are needed to drive sector growth and scale operations, capitalizing on climate opportunities. Our estimates show that 1.6 million of the four off-grid appliances discussed in this report were sold in 2023, against a serviceable market of 50 million appliances. Closing this gap will require billions of US dollars in funding over the next few years.

Key actions required from investors, development partners, and financiers include:

ENCOURAGE MARKET ENTRY

Deploy capital to encourage new company formation in underserved markets, driving innovation and expanding access to solar appliances.

FORM PUBLIC-PRIVATE PARTNERSHIPS

Developing programs that combine public funding with

private capital can help expand distribution networks and scale operations. For instance, British International Investment (BII) and Stanbic Kenya have invested in the off-grid solar company Sun King through a \$130 million USD funding round and a joint \$20 million USD working capital facility. This local securitization deal provides a capital boost to the off-grid solar sector in Kenya and enables Sun King to expand its pay-as-you-go (PAYGo) business (see case study 11).

CASE STUDY 11

SUNCULTURE AND BBOXX-EDF TOGO²⁰⁹

In 2019, SunCulture and Bboxx-EDF Togo launched a pilot project to deliver 30 productive-use solar assets to smallholder farmers in Togo. The initiative aimed to demonstrate the efficacy of SunCulture's solar technology for enhancing local agriculture and showcase its value to the Togolese Ministry of Agriculture. Following the pilot's success, a more extensive public—private partnership (PPP) was formed, resulting in a memorandum of understanding to deploy 5,000 solar irrigation systems. These systems were subsidized by 50% through Togo's Support Programme for Vulnerable People (Programme d'appui aux Personnes Vulnérables, or PAPV), led by the Ministry of Agriculture using the existing CIZO platform for PAYGo systems.²¹⁰

Key lessons and successes from the partnership:

- **Government-led subsidies with private-sector sales:** The Togolese government facilitated 50% subsidies, making solar irrigation systems more affordable for farmers. SunCulture supplied the technology and training, while Bboxx-EDF

Togo managed distribution through its Pulse[®] super platform, efficiently connecting farmers with life-changing solutions. The government's active involvement was essential in attracting leading companies like SunCulture to small and underdeveloped appliance markets like Togo. This strategy has also drawn companies like SunKing, which has further invested in the region by acquiring a smaller solar home system company.

- **Importance of raising consumer awareness:** Significant investments were needed to raise consumer awareness in Togo, a critical step given the initial low levels of local awareness on the basics of irrigation and the complexities of new technology.

Refined approach to sales: Selling solar water pumps requires setting up a dedicated expert team with the right technical know-how. Standard solar home system sales teams struggled with the longer, more complex sales cycles and product fit issues. While government support is critical for promoting the product and raising awareness, the sales and distribution process must be farmer-led and driven by the private sector. This approach prevents issues such as overselling and ensures a better fit between products and farmers' needs. In addition, when PAYGo financing is utilized, a distributor-led sales strategy enhances sustainability of the model. ■

INTEGRATE WITH CLIMATE FINANCE

Leveraging carbon credits and other climate finance mechanisms can help lower the cost of solar appliances, making them more affordable for consumers. (See case study 12.)

SUPPORT DOMESTIC CURRENCY LENDING

Providing local currency debt financing is crucial to mitigate the risk of currency fluctuations and make investments more attractive for developers. For example, M-KOPA recently secured the IFC's first sustainability-linked loan to a PAYGo provider in sub-Saharan Africa, which will help expand its financial services to underbanked consumers.²¹²

PURSUE UTILITY-ENABLED FINANCE

Partnerships between utilities and PAYGo providers can help expand access to appliance financing for grid-connected customers. Utilities have vast reach, rich consumer data, and established payment channels, while PAYGo companies have experience in consumer finance and appliance bundling.²¹³

PROVIDE INNOVATION FUNDING

Provide funding and resources for local technology innovators to develop solar appliances that meet the specific needs of off-grid consumers. Since 2018, the Efficiency for Access Research and Development

Fund, supported by IKEA Foundation and UK Aid, has provided £5 million GBP across 38 R&D projects, accelerating innovation in the off-and weak-grid appliances sector. EforA's [2024 Agritech call](#) was massively oversubscribed, receiving 132 applications requesting over \$24 million USD in funding. Similarly, the recent call by Powering Renewable Energy Opportunities (PREO) shortlisted 241 applications that sought a combined \$50.8 million USD in catalytic grants for a fund that had only \$3 million USD.²¹⁴

SUPPORT PILOT PROGRAMS AND BUILD ECOSYSTEMS OF SUPPORT

Support pilot programs to enable innovators to test new solar appliance technologies in real-world settings before large-scale deployment, as well as the development and promotion of sustainable business models. Initiatives like the Global LEAP Awards provide recognition, funding, and market access to emerging solar appliance technologies, fostering a supportive ecosystem for innovation.

BUILD A SUSTAINABLE WORKFORCE

Support innovators in building the ecosystem for a sustainable workforce by funding, training, and capacity building for local technicians and maintenance personnel, ensuring they have the

CASE STUDY 12

CARBON FINANCE: ENNOS AND INNOVEX

Ennos Ag has partnered with Innovex and Carbon Clear to integrate PayGo technology with carbon credit generation for solar water pumps.²¹¹

In the quest to provide sustainable water solutions and reduce carbon emissions, Alliance for Rural Electrification (ARE) member Ennos has teamed up

with Innovex Uganda and CarbonClear to offer an innovative approach integrating PAYGo technology with carbon credit generation for solar water pumps. This partnership brings significant benefits to both local users and global CO₂ emitters.

Ennos.ch is a Swiss company dedicated to creating sustainable water solutions. Its flagship product, the sunlight pump, is an efficient surface solar-powered water pump designed to meet the needs of small-scale farmers and remote communities. By integrating Innovex's REMOT device, ennos.ch enables a seamless PAYGo system that allows users to pay for water in flexible installments, making the technology accessible and affordable, as well as calculating CO₂ savings. ■

necessary skills to install, maintain, and repair solar appliances. The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain Systems (ACES), developed through a collaboration between UK, EU, and African universities, has a large training component to support the development and deployment of sustainable solutions to cold-chain challenges.²¹⁵

ADVOCATE FOR POLICY SUPPORT

Support engagement with policymakers to ensure favorable tax regimes, subsidies, and incentives for solar appliance adoption.

TECHNOLOGY INNOVATORS: DRIVE INNOVATION AND LOCAL RELEVANCE

Continued innovation in energy efficiency and cost reduction for increasingly energy-intensive appliances like those highlighted in this report is essential. Developing standardized communication protocols and ensuring interoperability across different systems will reduce costs and improve customer experience. A key challenge, however, is that off-grid solar consumers often use technologies designed by companies far removed from their context. Additionally, there is limited support for local technology innovators and insufficient acknowledgment of indigenous knowledge that can enhance technology design. Limited availability of R&D funding further hinders growth and iteration.

Key actions to address these issues include:

ENHANCE PRODUCT DURABILITY AND RELIABILITY

Focus on enhancing the durability, repairability, and reliability of solar appliances to ensure long-term customer satisfaction and reduce maintenance costs. Incorporate user feedback and rigorous testing standards to improve product design and lifespan.

PRIORITIZE LOCAL CONTEXTUALIZATION

Prioritize local contextualization of solar appliances to ensure they meet the specific needs of off-grid consumers. This involves understanding the local culture, climate, and energy requirements in order to design appliances that are fit for their purpose. Furthermore, innovators should recognize and incorporate indigenous knowledge and expertise in the design and development of solar appliances. This can help improve the effectiveness and relevance of the technology, while collaborating with local stakeholders in the design process will improve responsiveness.

DESIGN FOR GENDER AND SOCIAL INCLUSION

Ensure that the design and deployment of solar appliances are inclusive, addressing the needs of women, persons with disabilities, and other marginalized groups.

LEVERAGE DATA AND ANALYTICS

Utilize data and analytics to better understand consumer behavior, energy usage patterns, and market trends.

ENTREPRENEURS AND VENTURE BUILDERS: INNOVATE ON BUSINESS MODELS

Developing a more holistic approach to business model innovation can overcome affordability issues while improving company performance. For example, Oorja Development Solutions' water-as-a-service model in India demonstrates how innovative business models can improve affordability and access for low-income farmers.

To drive growth in the off-grid appliance market, venture capitalists and entrepreneurs must diversify funding sources and develop creative business strategies. Key actions include:

EXPAND PAY-AS-YOU-GO (PAYGO) MODELS

Promote the expansion of PAYGo models and diverse payment options like pay-per-day and pay-per-use to enhance affordability and access for low-income households. Explore energy-as-a-service models that encourage better maintenance and support.

LEVERAGE CATALYTIC GRANTS AND SUPPORT PROGRAMS

Utilize catalytic grants and support programs to innovate business models and foster partnerships. CLASP's Productive Use Finance Facility offers funding and resources to reduce risk for companies entering new markets or scaling their existing product lines. The Powering Renewable Energy Opportunities (PREO) Program provides catalytic grants to support business model innovation, stimulate partnerships, and accelerate the use of renewable energy across various sectors. This type of funding supports de-risking of future investments. Furthermore, employment of blended finance approaches that mix concessional loans, grants, and equity investments are needed to support companies in scaling operations and reaching underserved markets.

PROMOTE PARTNERSHIPS IN THE SUPPLY CHAIN

By focusing on specific product categories or value

chain segments, companies can develop deeper expertise and more cost-effective solutions. For example, Koolboks, a company that specializes in off-grid refrigeration solutions, partners with solar home system companies to integrate its refrigeration products into their offerings. Another company, Ecozen, focuses on developing and manufacturing solar-powered irrigation and cooling solutions for the

agricultural sector and works with local distributors to reach farmers. This kind of specialization allows companies to innovate more effectively, form strong partnerships, and make products more affordable for off-grid communities.

Entrepreneurs can also collaborate with established manufacturers to produce solar appliances under



Manual hand pump in Kenya. Switching to solar pumps allows easier access to water

their own brands, reducing costs and accelerating market entry. This approach will enhance efficiency and expand market reach.

ALL MARKET ACTORS: UNDERSTAND CONSUMERS AND MEASURE IMPACT

Effective monitoring and evaluation are crucial for the success of the off-grid appliance sector. However, these processes should prioritize consumer benefits and minimize data collection intrusiveness. Additionally, appliance users should directly benefit from the data collected. Encouraging more learning and data sharing can avoid redundancies, ensure efficient and equitable funding distribution, and minimize over-extraction of information from end consumers.

Key actions include:

PRIORITIZE USER-CENTRIC DATA COLLECTION

Collect data that directly benefits appliance users, minimizing intrusiveness by leveraging IoT. Offer consumers incentives like discounts or free maintenance services in exchange for participation in data collection initiatives, ensuring that they see

tangible benefits from their involvement.

HARMONIZE METHODOLOGIES FOR MEASURING PROGRESS

Development agencies should work closely with governments to establish mechanisms for tracking progress toward electrification and appliance access goals. Harmonizing methodologies and making them available as public goods is essential. Creating standardized tracking systems similar to those used in national census programs can provide reliable data for assessing progress and informing policy decisions.

FACILITATE DATA SHARING, PROMOTING TRANSPARENCY AND ACCOUNTABILITY

Development agencies and philanthropies can facilitate the dissemination of best practices and successful case studies through conferences, workshops, and publications. Grantees should be encouraged to share information about their successes and failures. A culture of transparency and accountability in data collection and usage should be encouraged, making data available to all stakeholders to inform decision-making and policy development.



Solar-powered fans in an electronics shop in Barisal, Bangladesh



Solar water pump customer in Ghana

Photo Credit: Aggrico

ANNEXES

ANNEX 1

Efficiency for Access worked with [Advancing Green](#) and [Catalyst Energy Advisors](#) to develop market sizing models for Kenya, Nigeria, and India. These models are intended to help the sector converge around an approach for modeling addressable and serviceable appliance markets.

MARKET SIZING SPREADSHEET TOOL:

These tools allow users to explore the addressable and serviceable markets for fans, refrigerators, solar water pumps, and grain mills. The results are displayed on the Dashboard tab. The spreadsheets also include the functionality to vary appliance prices, payment terms, and income levels to illustrate the impact of those variables on market size. For instructions on how to use these tools, see the Cover Page tab in each model.

Download the spreadsheet tool for each country using the links below:

[India](#)
[Kenya](#)
[Nigeria](#)

Global extrapolation calculations:

The global addressable market was estimated using linear extrapolation from the cumulative results obtained from India, Kenya, and Nigeria.

[Download](#) the calculations for the global addressable market.

The global serviceable market was estimated using income distribution data for 20 countries representing 75% of the global unelectrified population to evaluate for affordability. The cumulative results obtained from those 20 countries were then extrapolated for global insights.

[Download](#) the calculations for the global serviceable market.

DISCLAIMER

It is challenging to draw clear conclusions due to limited data on key variables including:

- solar appliance sales from non-GOGLA-affiliate companies,
- higher-performing solar appliance retail prices in different countries
- access and availability of solar appliances in remote, rural off-grid areas

As a result, we based our estimations on a set of assumptions outlined clearly within the individual models. Our approach, while methodologically sound, is subject to inherent limitations and uncertainties. The results should therefore be interpreted with caution. ■

ANNEX 2

Table 9: Off-grid appliance sector stakeholders consulted for this report and contributing research

	ORGANIZATION	COUNTRY/REGION
1.	Oorja Development Solutions Limited	India
2.	Promethean Power Systems	India
3.	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)	India
4.	Global Off-Grid Lighting Association (GOGLA)	Global
5.	The World Bank	Global
6.	NSB-NTPC School of Business	India
7.	CLASP	India
8.	Teri	India
9.	Council on Energy, Environment and Water (CEEW)	India
10.	Ecozen	India and Africa
11.	Third Wave Power	India
12.	New Leaf Dynamic	India
13.	KPay	India
14.	D.Light	Global
15.	SunKing	Global
16.	Devidayal Solar Solutions Pvt. Ltd	India
17.	DOB Equity	East Africa
18.	Novastar	Africa
19.	Triple Jump (Energy Entrepreneurs Growth Fund [EEGF])	Africa
20.	Cygnum Capital	Africa
21.	Mirova SunFunder	Global
22.	The Currency Exchange (TCX)	Global
23.	Simusolar	East Africa
24.	InspiraFarms	Kenya
25.	Nigeria Rural Electrification Agency (REA), Energising Agriculture Program	Nigeria
26.	Nigeria Off-Grid Market Acceleration Program (NOMAP)	Nigeria
27.	United Nations Development Programme (UNDP) Africa Mini-Grids Program	Nigeria
28.	Koolboks	Nigeria
29.	Pet-Feb	Nigeria
30.	Community Energy Social Enterprise Limited (CESEL)	Nigeria
31.	Husk	Nigeria

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CONTACT US

 efficiencyforaccess.org

 info@efficiencyforaccess.org

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