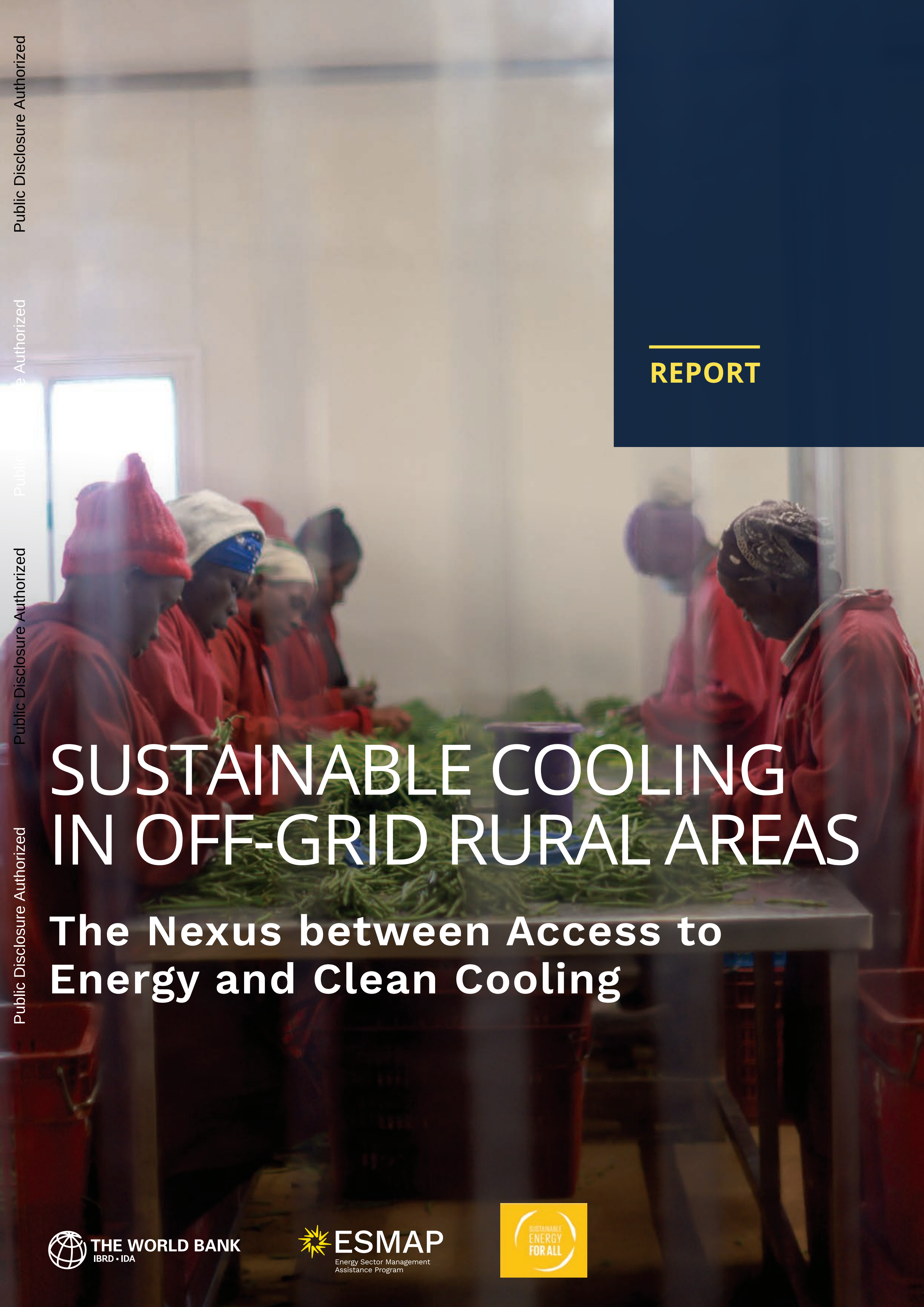

REPORT

SUSTAINABLE COOLING IN OFF-GRID RURAL AREAS

The Nexus between Access to Energy and Clean Cooling

THE WORLD BANK
IBRD • IDA

ESMAP
Energy Sector Management Assistance Program

SUSTAINABLE ENERGY FOR ALL

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ABOUT ESMAP

The Energy Sector Management Assistance Program (ESMAP) is a partnership between the World Bank and over 20 partners to help low- and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable, and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets. Learn more at: https://esmap.org

ABOUT SEforAll

Sustainable Energy for All (SEforALL) is an international organization that works in partnership with the United Nations and leaders in government, the private sector, financial institutions, civil society and philanthropies to drive faster action towards the achievement of Sustainable Development Goal 7 (SDG7) – access to affordable, reliable, sustainable and modern energy for all by 2030 – in line with the Paris Agreement on climate. We work to ensure a clean energy transition that leaves no one behind and brings new opportunities for everyone to fulfil their potential.

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Front Cover | InspiraFarms cold rooms seen through the strip curtain in Kenya. *Source:* Timothy Mwaura.

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Abbreviations

AC	alternating current
ACES	Africa Centre of Excellence for Sustainable Cooling and Cold-Chain
BASE	Basel Agency for Sustainable Development
CaaS	cooling as a service
CIF	Climate Investment Fund
CLASP	Collaborative Labelling and Appliance Standards Program
DC	direct current
ESCO	energy service company
ESMAP	Energy Sector Management Assistance Program
GAVI	Global Alliance for Vaccination and Immunization
GHG	greenhouse gas
GOGLA	Global Off-Grid Lighting Association
GWP	global warming potential
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
HFC	Hydrofluorocarbon
m3	cubic meter
MEPS	minimum energy performance standard
MTF	Multi-Tier Framework
NAP	National Adaptation Plan
NCAP	National Cooling Action Plan
NDC	Nationally Determined Contribution to the Paris Agreement
O&M	operation and maintenance
OGS	off-grid solar
PAYG	pay-as-you-go
PCM	phase-change material
PV	photovoltaic
QA	quality assurance
SDD	solar direct drive
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All
SHS	solar home system
TA	technical assistance
UNICEF	United Nations Children's Fund
WHO	World Health Organization
Wp	watt-peak

All currency is in United States dollars (US$, USD), unless otherwise indicated.

Preface

Approximately 306 million poor rural people in 2023 faced health and productivity risks due to a lack of access to cooling that are certain to increase as global temperatures rise (SEforALL 2023). Despite global efforts to increase electricity access, about 540 million rural people still lacked access to the electricity needed for quality of life in 2021, including the need to power cooling equipment (IEA et al. 2023).

People living in rural areas with no access to the electricity grid (off-grid areas) find it difficult to access all types of essential infrastructure, including cooling infrastructure. Addressing the nexus between access to electricity and access to sustainable cooling for people in off-grid areas represents a unique opportunity to advance the Sustainable Development Goals and the just and inclusive energy transitions called for by the Paris Agreement through expanding access to both services.

Off-grid electricity provision has made significant strides recently; of the estimated 493 million people accessing electricity through solar energy kits/systems in 2022, a majority lived in rural areas (Lighting Global/ESMAP, GOGLA et al. 2022b). Governments and the development community have been accelerating work to develop and promote cooling technologies that can work with off-grid power sources such as these stand-alone solar systems. Access to such off-grid cooling technologies can help meet critical cooling needs, for example, by powering fans to provide families and workers with relief from heat as well as refrigerators or cold storage rooms to preserve food quality, support livelihoods by extending the life of produce, and store critical vaccines.

ESMAP's Sustainable Cooling Program and SEforAll prepared this report to stimulate discussion and action among stakeholders on the urgent need for significantly more attention to the nexus of access to sustainable cooling with access to electricity in rural off-grid areas.

Based on a literature review and electrification experiences on the ground, the report seeks to clarify key concepts related to cooling needs and opportunities in rural off-grid areas and the synergies between access to cooling and to electricity, identify important issues and barriers along with policy tools to address them, and, finally, based on this initial assessment, formulate preliminary recommendations and signal areas for further work.

The target audience consists of policy makers and managers in governments and development partners working on access to energy and sustainable cooling, as well as private electricity service providers and firms active in cooling industries, and stakeholders in sectors where cooling plays a key role (including energy, agriculture, health, as well as climate change and the environment).


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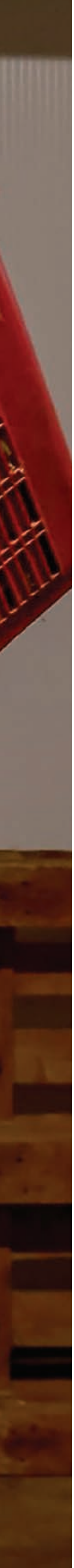


Acknowledgements

The conceptualization of this report was developed by Leo Blyth (Sr. Consultant, ESMAP/World Bank) and Ben Hartley, (Program Manager, Cooling for All, SEforAll), who laid the groundwork to determine the inter-relationships between the main elements of the rural energy/cooling nexus and also led the report's drafting by an excellent team. At SEforALL, the report's production was supported by Giorgia Pasqualetto, Rosa Garcia, Alan Miller, Jem Porcaro, Brian Dean, and Alice Uwamaliya. Support was provided on the World Bank/ESMAP side by Daron Bedrosyan who provided initial oversight and guidance, and by Sushmita Singha who identified and integrated many key references. Ian Crosby completed the challenging job of bringing together all the rich material in the first draft and building the narrative. Further contributions were made by: Connor Cobb who led the integration of peer reviewers' feedback and prepared the study cases presented in Appendix A, Selçuk Tanatar who oversaw the preparation of the Box on Tech Emerge and Jen Lynch who prepared the Lighting Africa/Global program summary.

The work was initiated under the leadership of Martina Bosi and Rahul Srinavasan and subsequently guided by Jenny Hasselsten and Clemencia Torres de Mästle as co-leaders of ESMAP's Efficient and Clean Cooling Program. Susan Bogach reviewed the report and contributed to revising the final text. Siddika Bhuiyan Mishu provided assistance during the last phase of finalization of the manuscript.

This report could not have been written without the assistance of many individuals in and outside the World Bank who shared their valuable knowledge on the nexus of cooling and electrification in off-grid areas of developing countries. The authors would like to express to all of them their most sincere gratitude.

A wealth of information has become available in recent years from groups working on all aspects of cooling, including cooling requirements, equipment innovations, business and financing models, affordability, performance and impact. We would like to thank in particular: 1. SEforALL for their Chilling Prospects series which served as an excellent foundation for our work; 2. Efficiency for Access for their many published reports which were cited extensively throughout this report, most notably their unique insights on the status of off-grid appliance markets, technology briefs, sales and impact data, as well as appliance use cases and cost studies; and 3. ESMAP's Lighting Global/Africa program for their publications and information on solar lighting kits, power systems and off-grid appliance markets, which were very useful in this analysis.

The report was considerably strengthened through the insightful comments and suggestions provided by external and internal reviewers. This occurred first informally with: Bas Hettersheid (Wageningen University & Research), Charlie Miller (ESMAP/World Bank), Chris Beland (EST), Jakub Vrba (EST), Makena Ireri (CLASP), Riley McDonald (CLASP). It was followed by a formal peer review with: Martina Bosi (World Bank), Raihan Elahi (World Bank), Roberta Evangelista (BASE), Ana Kojakovic (FAO), Maria Michela Morese (FAO), Manas Puri (FAO), Luis Rincón (FAO), Rahul Srinivasan (SEforAll), and Veljko Vorkapic (FAO).

At the World Bank, Demetrios Papathanasiou, Global Director, IEEDR, Gabriela Elizondo Azuela and Chandra Govindarajalu, former and current Practice Managers of ESMAP provided strong leadership, encouragement and support throughout the preparation and review of the report.

The report was edited by Fayre Makeig who helped to accomplish the difficult task of making it more readable read without losing substance and technical knowledge. Heather Austen, (ESMAP Communications) effectively guided the team through the publication process that transformed the manuscript into a well crafted report that we hope readers will find useful.

Executive Summary

This report aims to increase awareness and start a discussion among stakeholders on several important but little explored topics: access to efficient and clean cooling in off-grid rural areas, its nexus with access to electricity, and the synergistic development impact of addressing both needs. Efforts on cooling services have predominantly focused on urban rather than rural areas, where cooling needs have been largely unseen and unmet.

This report focuses on three types of cooling needs in off-grid rural areas: (1) human safety and comfort; (2) agriculture and food security; and (3) health care. Based on a literature review and electrification experiences on the ground, it seeks to clarify key concepts related to cooling needs and opportunities and the synergies with access to electricity, identify important issues and barriers along with tools to address them, and, based on this initial assessment, formulate early recommendations and signal areas for further work.

Situated at the nexus between access to electricity and cooling in off-grid rural areas, the report's audience consists of policymakers and project managers in governments and development partners advancing access to energy and sustainable cooling, as well as private actors in electricity and cooling sectors, and stakeholders in related sectors (including agriculture, health care, climate change, and environment).

Sustainable Cooling Is Critical for Off-Grid Rural Communities

Cooling infrastructure is critical for the basic essentials of life such as food and health, and to provide safe environments to live, work, learn, and play (Fox, Sayin, and Peters 2023). Lack of cooling access exposes the residents of high-temperature rural off-grid areas to many challenges, which affect their health, quality of life, and productivity. Poor ventilation, poor construction, and a lack of cooling appliances such as fans result in high indoor temperatures in homes and workplaces, jeopardizing human health and safety. Significant volumes of food production (fruit and vegetables, dairy products, meat and fish) are wasted due to spoilage resulting from lack of cold storage; this in turn limits rural incomes and contributes to food insecurity. Vaccines and other medications become ineffective when exposed to high temperatures or are unavailable due to a lack of cold storage. Insufficient access to reliable electricity in high-temperature rural areas hinders economic development, climate resilience, and efforts to meet other basic needs. Meanwhile, rural residents typically have lower incomes and fewer public or communal resources to invest in sustainable cooling than urban residents (AfDB 2022). Women and girls face specific challenges in accessing cooling services due to factors such as poverty, household and workplace dynamics, and access to health care and nutrition.

Climate change is exacerbating the adverse impacts of the lack of access to cooling (IPCC 2022). Difficulties coping with extreme heat outdoors and in homes, schools, and small businesses were already faced by half the global population for at least 30 days in 2023 (Climate Central 2023). These difficulties will increase as heat waves become more frequent and intense. Among the regions with acute lack of cooling and electricity access, by 2030, heat stress in agriculture will lead to a 92 percent loss of the total working time in Central and East Africa, 87 percent loss in the Pacific Islands, and 75 percent loss in West Africa (Saget 2023). The United Nations Environment Program estimates that 17 percent of total global food production was wasted in 2019, including from spoilage partly due to lack of cooling, contributing to food insecurity and adversely impacted farmers' livelihoods (UNEP 2021). Already in 2020, 98 million more people than in previous years were affected by food insecurity because of the effects of extreme-heat and drought (Lancet Countdown 2022); women are more likely than men to experience moderate or severe food insecurity (FAO 2022). On the other hand, it is estimated that unlocking cold chains in agriculture could enable developing countries to boost food supply by 15 percent (NextBillion 2020).

Advances in Technology are Opening New Opportunities for Sustainable Off-Grid Cooling if Availability and Affordability Issues are Addressed

SEforALL estimates that 306 million poor rural people are facing health and productivity issues from lack of access to cooling; contributing risk factors include no access to electricity and poverty level incomes below US$2.15 per day. While not all these people may live in off-grid areas, it is likely that most do. These are the most vulnerable people, who need the most support to benefit from cooling services. There is a second group of people who could benefit from off-grid cooling interventions: these are the majority of the estimated 493 million people with access to electricity provided by solar electricity kits who live in off-grid rural areas and could potentially buy cooling equipment with an upgrade to increase their systems' capacity beyond supporting lighting and phone charging (Lighting Global/ESMAP et al. 2022b).

Significant advances in off-grid electrification technologies and off-grid appropriate cooling appliances are opening game-changing opportunities to meet long unmet needs for space cooling and refrigeration in off-grid rural areas. These advances put access to sustainable cooling solutions within reach for those gaining access to electricity in off-grid settings, including those using solar energy kits. However, experience with expanding off-grid electricity access has shown that a holistic approach to improve technologies, business models, access to finance, capacities, policies and more is necessary to create the enabling environment needed to realize the potential of off-grid cooling solutions for poor people in rural areas. Looking to the future, off-grid solar is estimated to be the least-cost choice for 41 percent of all new household connections between 2020 and 2030 (Lighting Global/ESMAP et al. 2022b).

There have also been rapid improvements in the efficiency, performance, and cost of off-grid cooling appliances and equipment, from fans to refrigerators and freezers, to walk-in cold storage rooms and milk chillers. Taken together, these improvements to appliances dramatically increase the range of off-grid cooling services available. While passive solutions can bring substantial benefits without requiring electricity, active cooling measures require specialized cooling appliances, often using DC (direct current) motors (in contrast to the AC [alternating current] motors used in on-grid equipment) that can be used with solar systems or powered directly by solar panels. The key off-grid cooling technologies are at varying stages of commercialization, as discussed below. There is enormous potential and need for more programs, projects, and activities to develop off-grid cooling technologies further and make them more available and affordable for rural people.

To meet sustainably the electricity and cooling needs of people living in off-grid areas, while contributing to climate adaptation and mitigation, efforts to increase access to both cooling and electricity need to utilize renewable energy sources and efficient equipment while minimizing high-hydrofluorocarbon (HFC) refrigerants to avoid increasing GHG emissions. Access to sustainable cooling solutions in off-grid areas also hinges on the availability of skilled engineers to design and install larger facilities at the national level and technicians to install and maintain all types of off-grid cooling equipment at the local level.

Business Models Demonstrate how to Accelerate Access to Sustainable Off-Grid Cooling

Innovative business models are beginning to demonstrate how cooling and electricity access can be accelerated for rural off-grid communities (see Table ES.1 and Appendix B for full details). One approach to market transformation for electricity access is for the public sector to create an enabling environment (including facilitating access to finance) while the private sector creates the commercial mechanisms to implement activities to expand access, as with the Lighting Global program. The private sector is demonstrating innovation and initiative in addressing key challenges surrounding affordability/high up-front costs and adequate consumer protection (e.g., quality control, warranties, and after-sales service). Market models such as pay-as-you-go (PAYG); cooling as a service; on-bill financing; dealer financing; leasing; and access to loans for operators, consumers, and energy service companies (ESCOs) aim to make electricity services more affordable. These models help to reduce up-front costs by spreading payment over a longer term or shifting the ownership of assets from clients/end users to distributors/operators or to a third party, which then charges a fee for service. While these models increase affordability to the end-users, they also pose financing challenges for operators since asset costs are only recovered over time.

Cooling Technologies Improve Safety and Comfort in Off-Grid Rural Areas

High ambient temperatures affect productivity, physiological and psychological health, and can even cause death. Outdoor workers, farmers, pregnant women, children, the elderly, and those with weakened immune systems, who make up most of the population, are at increased risk. Livestock and animals also suffer from heat inside structures. Availability of cooling indoors is important for human and animal safety and comfort.

TABLE ES.1

Main Business Models for Off-Grid Cooling Services

TYPE	FEATURES AND SECTORAL USAGE	OWNERSHIP
Direct Purchase Equipment	A customer acquires cooling equipment from a seller upon payment in full. Or, an intermediary may pay for equipment and donate it to end users or groups of users (e.g., farmer cooperatives). Service and maintenance must not be forgotten. **Sector.** Residential space cooling, cold storage and space cooling for health care, and agriculture (micro, small, and medium enterprises). Typically, high prices severely restrict widespread adoption.	A single end user or customer, or an organization serving multiple end users.
Pay-As-You-Go (PAYG)	A customer purchases a cooling appliance/service and pays over time; a small extra payment is made to the supplier. This model is popular for off-grid solar and is also known as "rent to own" as the customer ultimately owns the product. **Sector.** Consumer space cooling appliances such as off-grid fans alone or bundled with solar system kits or upgrades. Off-grid refrigerators and freezers used by farmers, households, and microenterprises for agriculture-based and retail purposes. Financing is carried by the seller who needs access to low-interest/long-term loans to match the payment profile for low-income users.	The end user owns the product once repayment is complete.
Cooling as a Service (CaaS)	A cooling service provider delivers refrigeration services in return for a fee as per the customer's usage. The service provider invests in infrastructure and is responsible for its maintenance and operation. **Sector.** Agriculture, where produce is stored in walk-in cold rooms. Considered in health care but not widely adopted for storing vaccines and medicines. Financing carried by the operator who needs access to low interest/long term loans to match the payment profile for low-income users or government beneficiaries.	Service provider owns the asset throughout and the customer buys access to it.
Dealer Financing/ Leasing for Equipment or Facility	A financial institution/dealer funds a cooling service enterprise through a finance leasing agreement, with the cooling system used as collateral. **Sector.** Space cooling, agriculture, and health facilities. The financial institution/dealer carries financing and needs concessional financing to offer affordable terms to the service provider.	Financier or dealer during lease, service provider after repayment
Community Cooling Hubs Provide Cooling Services	This model aggregates demand and creates ownership among end users through a community-based operation. Selected as a "game-changing solution" for the 2021 UN Food Systems Summit, these serve as hubs for agriculture cold storage and can serve a variety of cooling needs, for example, vaccine storage or protection during heat waves. **Sector.** Agriculture storage and potentially for medical cold storage.	Service provider, which is a community or group.

Passive cooling technologies are ready for public information campaigns, for consideration within cooling programs as well as building practices and codes, which could require, for example, cool roofs in all new buildings at least within public buildings. Before resorting to electrical appliances, cooling should be maximized through passive measures. *Cool roofs*, meaning roofs painted white, have been proven to reduce indoor temperatures by up to 5 degrees centigrade and to have similar costs to conventional roofs. *Vegetation, shading, natural ventilation and wind-induced cooling* for rural homes and buildings can also enhance indoor comfort and productivity affordably. Trees can provide shade and comfort indoors when adjacent to buildings. Where water is sufficient, green roofs, which are roofs partially or completely covered with vegetation, share many benefits with cool roofs. These measures can also be applied to shelters for livestock.

Off-grid fans (DC powered) are the most commercial and affordable off-grid space cooling appliances for wide-scale adoption in homes, farm buildings, microenterprises, and public buildings. Their benefits are highly valued; 81 percent of off-grid customers in Bangladesh reported that fans had improved their quality of life, besides extending daily productive time by over two hours (Efficiency for Access 2021d). While improvements are still expected in efficiency, performance, and cost, markets for fans powered by off-grid solar are developing fast. GOGLA, the Global Off-Grid Solar Association, estimates that its affiliates sold about 1 million off-grid fans worldwide in 2022 (GOGLA n.d.), indicating a possible global market of at least 2 million fans. Assuming that, like solar kits, the majority of these fans are sold to off-grid areas (Lighting Global/ESMAP 2022b), this represents only a small share of off-grid households. GOGLA reports the average cost of fans sold by affiliates as US$33–39 (see Table ES2 below). Given its estimate that the typical monthly income of rural customers is less than US$3.20/day it would take a rural person about 4 months to afford to buy a fan by saving 5 percent of income per month.

TABLE ES.2

Market Pricing for Commercially Available Off-grid Rural Cooling Technologies

SECTOR	APPLIANCE TYPE	SIZE	PRICE (US$)	INDICATIVE SUPPLIERS
Households/ Agriculture/ Enterprises	Refrigerators or freezers, or variable-temperature units (including a solar power and storage system)	<200 liters (L)	600–2,700	Devidayal, Koolboks, Palfridge, Sola-Run, Steca, SunDanzer, SureChill
		200–400 L	1,200–3,500	
		>400 L	1,240–3,800	
	Walk-in cold rooms (including a solar power and storage system)	<5 metric tons	10,000–50,000	Ecozen, Fresh Box, InspriaFarms, Self Chill
Space Cooling	Table fans	100–380 millimeters (mm)	8–61	d.light, Metropolitan, Royal, Solar Run, SunKing, Super Star, Tamoor, VersaDrives
	Pedestal fans	320–650 mm	17–62	
	Ceiling fans	1,000–1,400 mm	14–65	

Sources: Lighting Global/ESMAP et al. 2022b; According to Efficiency for Access 2024

Notes:
1. Pricing for refrigerators and freezers/variable-temperature units includes appliances of the size range that have power demands depending on their temperature and other variables.
2. Pricing for the first two appliance types—refrigerators/freezers and walk-in cold rooms—includes a solar power and storage system (using electrical batteries, "ice batteries" using phase-change materials, or a combination thereof).
3. The average price of a table fan was US$43, a pedestal fan was US$39, and a ceiling fan was US$38.
4. Pricing is at retail value in Sub-Saharan Africa (including taxes, duties, shipping costs, and profit margins).

Broad efforts to make off-grid fans more accessible for rural residents, together with solar kits or upgrades, if needed, could bring great benefits. Creating an enabling environment for increasing access to off-grid fans would require elements similar to those of the Lighting Global program (see Box 4.1), for example, awareness campaigns, quality assurance (standards, supplier warrantees, and compliance monitoring), and concessional financing to suppliers to help them build their business line and offer PAYG-type financing to customers. The approaches used in national solar promotion programs or the Lighting Global program could be extended to support access to off-grid cooling solutions. Given the low household incomes in off-grid areas, an up-front subsidy would be essential to reach the most vulnerable.

Cooling Technologies Support Agriculture, Food Security, Nutrition in Off-Grid Rural Areas

The vast majority of rural residents engage in agriculture, for example, subsistence farming, herding, or fishing. The United Nations Environment Programme estimates that 17 percent of the total global food production was wasted in 2019, contributing to food insecurity and adversely impacting farmers' livelihoods (UNEP 2021). Climate change is worsening the situation and will trigger more frequent, more intense, and more severe droughts and heat waves in the absence of or with limited mitigation (IPCC 2022). Elevated temperatures due to climate change will adversely impact crop yield and quality and compound water needs for irrigation; droughts will have the same impact. All of this will increase pressure on agricultural production and food insecurity (Calleja-Cabrera et al. 2020). On the other hand, developing countries can boost food supply by 15 percent through greater access to cooling facilities and cold chains that extend the life of produce (NextBillion 2020).

Domestic and light commercial off-grid solar refrigerators and freezers for use in homes, small shops, and agricultural production are already available in some markets (Lighting Global/ESMAP et al. 2022b). While units are typically of less than 200 liters in size, they can reach 400-liter volumes. Recent innovations are driving down costs and improving efficiency and durability (Efficiency for Access 2021f, 2022b), but high costs, uncertain quality, and inadequate service remain critical barriers. The in-country retail cost of such units is estimated at US$1,200–3,800, depending on size, taxes, and geographical and market factors (see Table ES.2). An estimated 7,400 refrigeration units were sold by GOGLA affiliates in 2022 (GOGLA n.d.); global sales by all suppliers are likely to be at least double this. Under VeraSol, global quality standards and field-testing standards are being developed for these off-grid units. Given the low-income levels among off-grid rural households and enterprises, domestic or micro-enterprise refrigerators and freezers are out of most peoples' reach, unless they have significant savings or income/profits from a business. The small sales volume of such appliances in off-grid areas indicate both the early stage of the technology and its limited affordability given high costs. These technologies are ready for demonstration and promotion to scale up use, but quality assurance will be essential, and significant subsidies may be required until costs come down and access to finance increases significantly.

Small-scale commercial off-grid agricultural refrigeration (e.g., cold rooms and chillers) holds great potential, although technologies in this area are still emerging and unproven in many markets. These technologies include walk-in cold rooms (including a small share of freezing rooms), milk chillers, ice makers, and electric chiller vehicles that are sized to serve producer cooperatives and for use in aggregation and distribution chains (USAID 2020).

Larger "facilities" such as walk-in cold storage rooms are still emerging technologies. These cold rooms range from ready-made "plug and play" units, to those flat packed and constructed on site, and those that are fabricated completely locally and require only the essential cooling and power components. They have high power requirements (typically 3,000–10,000 watt-peak (Wp)) and cost from US$10,000 to US$50,000 depending on size and location, see Table ES.2 (Efficiency for Access 2021a). Cold rooms typically require farmers to group together to purchase and operate the facility, or a commercial operator to sell services to farmers. While certain markets have shown significant progress—for example, there are over 1,000 walk-in cold rooms in India—others remain nascent—for example, in Sub-Saharan Africa there are only about 100 units.

Three main business models are currently used for these solutions: (1) cash purchase from retailers; (2) asset finance/leasing; and (3) cooling as a service (CaaS), where an operator owns an asset such as a cold storage room while the end user(s) pay(s) for services. Lighting Global has estimated markets for cold storage by smallholder farmers without access to the grid, assuming that farmers would group together. It estimated that 12 percent of farmers in Sub-Saharan Africa could afford to buy cold storage services (0.89 of 7.4 million) at a total facility cost of US$296 million. For India, it estimated that 30 percent of farmers (15.8 of 52.5 million) could afford to participate in storage facilities valued at US$3.1 billion (Lighting Global/ESMAP et al. 2022b).

While opportunities to reduce agricultural produce waste through off-grid storage technologies are great and the technologies are moving fast, major demonstration and promotion efforts are needed to unlock the huge potential. Such demonstrations could help both supply and demand drivers of scale by: (1) reducing high capital and operation and maintenance (O&M) costs through technology development and increased scale of production; (2) testing business models that permit affordable payment for a reliable service; (3) growing effective supply chains to ensure reliable O&M; (4) building a quality assurance system (standards, supplier-backed warranties, and compliance monitoring); and (5) stimulating demand through the demonstration effect amongst target users.

Cooling Technologies Contribute to Health Care in Off-Grid Rural Areas

Access to sustainable cooling in health care is vital for vaccine efficacy, blood product stability, the operation of critical medical equipment, and thermal comfort in hospitals and health centers in rural areas. Vaccine refrigeration is essential for immunization, one of the most impactful public health interventions, averting over 4 million deaths every year. The return on investment for immunization has been estimated at US$44 per dollar invested (WHO n.d.).

Solar direct drive (SDD) vaccine refrigerators have been widely used to replace less reliable liquefied petroleum gas-powered or kerosene-powered refrigerators since 2014, in areas with unreliable electricity service or without electricity (WHO 2017). Use of these refrigerators increased exponentially with the need to vaccinate populations for COVID-19. Analysis has shown that, while annualized costs of SDD refrigerators are double the cost of grid-powered refrigerators, they are 15 percent lower than those of fuel powered refrigerators, with no CO_2 emissions. SDD refrigerators can also outperform conventional refrigerators in locations with weak and unreliable grids (WHO 2017). However, powering all priority power needs of off-grid clinics requires larger, more expensive solar photovoltaic (PV) systems. Two paths have developed: (1) vaccine cold chains powered by solar alone or (2) solar electrification of all priority power needs off-grid health facilities. Most public projects have focused on bulk procurement of solar assets to lower costs through purchase on large scale; increased attention is needed for adequate O&M over equipment life. An ESCO is one way to address sustainability, by selecting a service provider (e.g., for installing and operating PV systems and the related equipment over 10–15 years) and paying for the services over a contract's life.

While the need is enormous and there are many demands on public funds, many governments and development organizations are working to address the twin challenges of providing electricity access and vaccine storage to health care facilities with off-grid solutions. Active partners include the World Bank/ESMAP, SEforALL, the United Nations Children's Fund, the Global Alliance for Vaccination and Immunization (GAVI), and the World Health Organization. Lighting Global reports that at least 30 countries, including São Tomé and Príncipe, Nigeria, Togo, Somalia, Indonesia, and the Kyrgyz Republic, have procured, or are procuring, cold chain equipment such as SDD refrigerators, using funds from such agencies in their COVID-19 response (reported in Lighting Global/ESMAP et al. 2022b).

Appropriate Policies Play a Key Role to Enable Scaling Up of Access to Sustainable Cooling

National level policies are being developed to support scale up of increased access to sustainable cooling, mainly focusing on urban areas and only beginning to include off-grid rural areas. First, there are efforts to integrate cooling access into national electrification strategies or integrated energy plans. Second, there is a need to integrate the cooling dimension in the policies and strategies of sectors that require efficient cooling to achieve their objectives, notably agriculture (including dairy and fisheries), health, and environment. Third, National Cooling Action Plans (NCAPs) increasingly seek an effective and all-inclusive approach to make indispensable life-saving services such as food and vaccine preservation accessible for all while targeting climate mitigation and adaptation goals. They can also provide critical support to ensure coordination and cooperation among government and stakeholders, and have been endorsed by the UN Secretary-General. Underpinning these policy and program efforts is the need for regulations, standards, and quality assurance, as well as cross-sector institutional support.

Financing Mechanisms are Needed to Secure Resources for Increasing Access to Cooling

Scaling up access to cooling in off-grid rural areas needs additional resources. Since sustainable cooling contributes to both climate change mitigation and adaptation, there is a possibility for related programs, projects, and activities to access climate finance. One example of climate financing specifically for cooling access is the Green Climate Fund's commitment to provide US$157 million to a new cooling facility at the World Bank, with an additional US$722 million in leveraged co-finance from World Bank projects. Other opportunities to finance access to cooling initiatives include the Global Environment Facility's Least Developed Countries Fund and Special Climate Change Fund, and the Climate Investment Fund's US$1.2 billion Pilot Program for Climate Resilience.

Results-based financing and bulk procurement are financing mechanisms of interest for sustainable cooling interventions. Results based financing disburses donor funding to an implementing party (e.g., a product distributor or service provider) based on a third-party-verified performance or "service delivery" against agreed-upon metrics (World Bank 2019). Program implementors (typically private companies) are motivated to deliver high-quality output at speed and scale while taking on the risk of output delivery. Bulk procurement involves a public or private institution aggregating the demand for a cooling device (such as a fan, refrigerator or even walk-in cold room) and placing a bulk order. This enables economies of scale and encourages the scaling of service and maintenance to be more attractive for suppliers. Bulk procurement has been used mainly for vaccine cold chains.

Quality Assurance is Essential to Improving Access to Sustainable Cooling

Cooling and cold storage equipment represents a significant investment for stakeholders, including off-grid households, farmers, and entrepreneurs, as well as larger organizations and governments. Substandard, inefficient, and inappropriate equipment could be financially devastating and could undermine the urgent acceleration of sustainable cold chain access, either because it fails to meet the needs of the users and results in a financial burden for poor rural consumers, or because inefficient equipment bought by those with limited means increases GHG emissions. Off-grid cooling appliance standards, if properly enforced, effectively support the scale-up of access to efficient and sustainable cooling appliances and facilities. All activities to promote sustainable cooling must ensure that the equipment financed meets these minimum performance standards or at least performance benchmarks, to limit growth in potential emissions. Quality assurance programs, including quality standards, warranties and compliance monitoring, are essential for long-term market acceptance.

Conclusions

This initial review of access to efficient and clean cooling in off-grid rural area and its nexus with access to electricity in off-grid rural areas suggests a number of conclusions.

- Residents of high-temperature rural off-grid areas lack access to cooling services; this has significant adverse impacts on their health, quality of life, and productivity.

- In 2023, 306 million rural people who lacked electricity access and had incomes below the poverty level of US$2.15 per day were considered to be at high risk due to lack of access to cooling (SEforALL 2023).
- Lack of cooling services results in diminished quality of life; loss of productivity and income in agriculture, homes, schools, businesses, and clinics; increased food insecurity due to spoilage; and leads to a lack or shortage of vaccines.
- Climate change will only worsen impacts from lack of cooling with, for example, temperature rise and increase in the frequency and intensity of heat waves and droughts, among other extremes.
- Use of passive cooling technologies should be maximized to take advantage of affordable cool roofs, green roofs, ventilation, shading and wind-induced cooling.
- Rapid advances in off-grid electrification and development of off-grid cooling appliances offer game-changing opportunities; the majority of the 493 million people enjoying electricity access via off-grid solar kits in 2022 live in off-grid areas and could utilize low-energy-consumption cooling appliances, with upgrades to solar kits if necessary.
- Off-grid fans are commercially available in many markets and highly valued by those that can afford them with users reporting improved quality of life and increased daily productive time.
- Recent innovations in off-grid freezers and refrigerators are driving down costs and improving efficiency and durability, but limited availability, high up-front costs, uncertain quality and poor levels of service remain critical barriers.
- Off-grid agricultural refrigeration facilities (e.g., walk-in cold rooms, and milk chillers) are emerging technologies with great potential. More efforts are needed to demonstrate these technologies' performance and the business models given the need to aggregate farmers' demands.
- To be sustainable, boosting cooling and electricity access must utilize renewable energy resources and efficient equipment, while minimizing use of global-warming-potential (GWP) refrigerants.
- Quality assurance programs for off-grid cooling equipment/facilities, including performance benchmarks, quality standards, warranties, and compliance monitoring, are essential to protect end users and increase the adoption of off-grid efficient and clean cooling equipment, as it has been for off-grid solar electrification.
- Off-grid sustainable cooling solutions offer both climate change adaptation and mitigation benefits, improving resilience by helping people and livestock cope with increasing heat stress, while improving livelihoods and food security and reducing GHG emissions through use of clean and efficient cooling off-grid cooling solutions that minimize GWP refrigerants.

Recommendations: A Call for Action

Already substantial and largely unmet rural off-grid cooling needs will only grow with higher temperatures, more pronounced heat waves, droughts, and other climate change impacts. **Despite the preliminary nature of this report, a key message is that order of magnitude increases in both focus and effort are needed to accelerate the rural off-grid nexus of**

access to sustainable cooling and clean energy, akin to the concentrated effort on advancing urban cooling. Critical stakeholders such as policymakers, private sector actors engaged in cooling, and development partners must demonstrate commitment and engagement. The report has the following early recommendations for these stakeholders that need to be developed through further work and knowledge sharing about activities to promote off-grid sustainable cooling and their results.

Policies, Plans, Programs, and Projects for Sustainable Off-Grid Rural Cooling

- Integrate activities to increase access to cooling into energy access, climate change, agricultural and health care policies, plans and programs.
- Adopt regulations, standards, and quality assurance to channel incentives and financing to high-quality, high-efficiency cooling equipment only, while minimizing use of high-GWP refrigerants.
- Implement institutional coordination at national and local levels through communities of practice with representation across ministries, civil society, and the private sector.

Innovation in Technology and Business Models for Sustainable Cooling

- Invest in pro-rural, pro-poor technology innovation by increasing public finance to create off-grid cooling technology solutions that are available and affordable for low-income rural consumers (SEforALL 2022d).
- Expand testing and application of business models to make sustainable cooling affordable to low-income rural consumers and provide durable capacity building and business analytics for suppliers and operators.

Financing Rural Off-Grid Sustainable Cooling Programs and Projects

- Improve access to finance for space cooling by increasing number of suppliers offering PAYG and using financial instruments, for example risk-sharing facilities to encourage local banks and leasing companies to support service providers or consumers, using results-based financing to offer direct subsidies to end-users as well as providing working capital finance to suppliers.
- Improve access to finance for agricultural cold chains by ensuring that smallholders receive an equitable return on investments in cooling technology while integrating PAYG and Cooling as service models with agri-finance, aggregating demand from small farmers and supporting suppliers with working capital finance.
- Improve access to finance for health cold chains by facilitating instruments such as bulk procurement combined with contracts for operations and maintenance service or the use of Energy Service Company (ESCO) models where a competitively procured company provides energy and cooling services over a 10 to 15-year period and the government pays for the service.
- Use blended finance, mobilizing small sums to catalyze substantial finance from development finance institutions, which can in turn leverage even greater funding from local banks, leasing companies, and investors.
- Leverage climate finance adaptation and mitigation; project sponsors need to delineate their projects' adaptation and mitigation elements to be able to tap into single-purpose funds.

Information, Awareness, and Capacity Building

- Expand and accelerate data collection to support strategic and project-level decision-making on increasing access to cooling services in off-grid areas; using an agreed common format.
- Conduct awareness campaigns via the press, radio, civil society, and locally appropriate communication methods to encourage the use of sustainable and efficient off-grid cooling equipment and its proper management.
- Build long-term institutional capacity in ministries and local authorities, as well as across the silos between ministries and authorities, for example, energy, agriculture, environment, health, finance, so that they can develop and execute activities to promote access to cooling, including through national cooling action plans (NCAPs).
- Support the development of a skilled labor force of technicians, engineers, and other professionals, to support cooling activities, including production, installation and maintenance of equipment and facilities, both nationally and locally including service capacity at the local level.

Key Steps to Increase Access to Sustainable Off-Grid Cooling Services

- Implement activities to improve access to off-grid sustainable cooling in programs, projects and pilots that are integrated into electrification and sectoral policies, plans and programs to increase potential impact. These activities need to use a programmatic approach to build an enabling environment, incorporating to the extent possible elements like those in the Lighting Global Program (see Box 4.1) including awareness creation, capacity building of suppliers, concessional financing to suppliers, quality assurance (standards, supplier-backed warranties, compliance monitoring) and end-user subsidies to reach the most vulnerable. Different technologies and markets need different blends of these elements. One size does not fit all.
- Promote use of **passive cooling measures** like shading, natural ventilation, blinds, wind induced cooling, traditional architectural practices and cool roofs through awareness campaigns and changes to building practices and codes.
- Increase promotion of commercially available **off-grid fans**, which can bring great benefits; support their sale through commercial suppliers following successful approaches used in national solar home system projects and promotional efforts under Lighting Global.
- Expand promotion of **off-grid agricultural/ light commercial refrigerators and freezers**, which are market ready but require scale-up and cost reduction, through activities to demonstrate effectiveness and increase use, incorporating appropriate levels of subsidy given the relatively high cost of the equipment.
- Increase promotion of off-grid **agricultural walk-in cold storage and similar emerging agricultural refrigeration technologies** that have tremendous potential to reduce waste, through demonstration and scale-up activities for both technologies and business models to aggregate farmers' needs affordably.
- Expand efforts already underway to provide **solar-powered vaccine refrigeration and off-grid electrification for rural health facilities** while improving sustainability through use of models such as ESCOs, under which companies provide ongoing services rather than equipment.


NATIONAL RURAL HEALTH MISSION
NRHM
राष्ट्रीय ग्रामीण आरोग्य अभियान
VACCINE VAN
istry of Health and Family Welfare
Government of India

ONE
INTRODUCTION

The objective of this report is to increase awareness and prompt a discussion among key stakeholders on an important development topic that has received insufficient attention to date: access to efficient and clean cooling in rural off-grid settings, its nexus with electricity access, and the synergistic development impact of addressing both needs. The report also highlights how sustainable cooling in rural areas can help mitigate the impacts of climate change and help rural communities adapt to changing climate conditions. It also highlights the challenges in realizing those benefits as the low-income levels of the off-grid population often make sustainable cooling unaffordable despite the significant potential benefits.

Based on a literature review and experiences on the ground, the report seeks to clarify key concepts related to cooling needs and opportunities in rural areas and the synergies with access to electricity. It identifies important issues and barriers along with policy tools to address them. Finally, based on this initial assessment, the report formulates some preliminary recommendations and signals areas for further work to advance cooling access.

Cooling infrastructure is critical to enable access to the basic essentials of life, such as food and health, and provide safe environments to live, work, learn and play. (Fox, Sayin, and Peters 2023). Residents of high-temperature rural areas face a wide variety of challenges due to the lack of access to cooling, including risks to human and livestock health and safety, food insecurity, lack of vaccines and other basic health care services. They also suffer loss of economic opportunities associated with a lack of cooling to permit longer life of perishable produce and the ability to transform it into higher value commodities. Finally, rising temperatures due to climate change have added new dimensions to the critical need for cooling, to advance economies' adaptation to evolving climate conditions (e.g., space cooling in public areas and in rural settings to combat heat waves, which endanger lives, or post-harvest targeted interventions for cooling produce).

Meanwhile, the dangers of using inefficient technologies to meet the growing cooling demand in an overheating world have been well documented. Evidence from China suggests that the country's rural electrification programs led to a surge in demand for refrigerators and air conditioners (IEA 2018). Rapid increase in the demand for cooling appliances not only causes a demand surge for electricity, it can also contribute significantly to increases in greenhouse gas (GHG) emissions, since refrigerators and air conditioners often use hydrofluorocarbons (HFCs), which are refrigerants with a high global warming potential (GWP), often hundred to thousand times higher than carbon dioxide. For these reasons, reducing GHG emissions by maximizing energy efficiency of cooling appliances and minimizing the use of GWP refrigerants for refrigeration and air conditioning are key to ensuring that cooling needs are adequately addressed for all while minimizing climate disruption.

As varied as the challenges are, access to off-grid sustainable cooling presents an opportunity to simultaneously advance sustainable development, climate adaptation and mitigation, as well as rural electrification. This opportunity exists because the demand for electricity, which is accompanied by a demand for associated services, including cooling (e.g., suppliers bundling sales of fan or refrigerators with solar kits for sale) and the development of new larger scale off-grid cooling technologies (such as walk-in cold storage facilities), adds to the demand for off-grid electricity systems. However, promoting access to sustainable cooling for rural populations without exacerbating climate change requires increasing their access to electricity using sustainable, renewable energy systems. Achieving this expansion, however, would involve overcoming major obstacles considering the limited availability and affordability of off-grid cooling equipment, the fact that both electrification and cooling have received less attention in rural than in urban settings, and the complex nature of the interventions needed in rural areas. It also requires intersectoral cooperation and coordination among the government institutions and other stakeholders engaged in sectors such as agriculture, energy, health, and the cross-cutting areas of environment and climate change. A concerted effort and substantially increased support are thus required if sustainable cooling is to be truly ensured for all (see Box 1.1 for definitions of key terms related to energy and cooling).

The target audience for this report includes stakeholders in charge of policies and projects to expand rural electrification, as well as stakeholders involved in sectors where cooling plays a critical role such as energy, agriculture, health, climate change and environment (e.g., policymakers, unit heads, and project managers in/of governments, development finance institutions, and development partners). It also includes private electricity services providers and firms active in cooling industries.

The report focuses on rural areas beyond the reach of the national grid, where off-grid solutions are needed to address the lack of access to electricity. It examines more specifically the situation and cooling needs of rural dwellers in the tropical and subtropical zones, while recognizing that other regions may face a different situation, for at least part of the year. The report identifies the major cooling needs of these rural populations. It highlights the need for sustained actions to accelerate access to efficient and clean cooling for these communities and provides initial guidance on the best practices to capitalize on the opportunities of the nexus between electricity and cooling access.

The report is divided into six sections, including this introduction as Section 1. Section 2 outlines the nexus of access to sustainable cooling and electricity access. Section 3 discusses the status of technologies for cooling and electricity access and relates the Multi-Tier Framework for energy access to cooling technologies. Sections 4 and 5 describe experiences with emerging approaches to creating sustainable cooling programs that are relevant to rural off-grid areas. Section 4 deals with business models and finance and Section 5 discusses policies and enabling activities, including regulations, standards, and quality assurance, as well as capacity building and training. Section 6 provides conclusions and offers recommendations to accelerate the pace of progress to increase access to cooling and electricity in off-grid areas.

BOX 1.1

DEFINITIONS OF KEY TERMS

Sustainable cooling can be understood as the provision of access to cooling solutions that are environmentally sustainable, efficient, and affordable, as well as sufficient to meet the local demand for cooling, thus discouraging their potential overuse (SEforALL 2018). Multiple sustainable cooling solutions exist, whose readiness for commercial adoption varies. Achievement of global climate objectives and the Sustainable Development Goals requires sustainable cooling solutions to gain significant traction. These include: measures to reduce the need for cooling through insulation, shading, reflectivity, or ventilation; the most efficient fans, air conditioners, and refrigeration or freezing equipment for both domestic and commercial use; and collaborative development of more sustainable products, services, policies, and financial solutions to meet cooling needs and provide cooling benefits (SEforALL 2020a).

Modern **energy access** does not have a single internationally accepted and internationally adopted definition. Yet, the multiple definitions have much in common, including:

- Household access to a minimum level of electricity and the services it supports.
- Household access to safer and more sustainable (i.e., minimum harmful effects on health and the environment possible) cooking and heating fuels and stoves.
- Access to modern energy that supports productive economic activity across many segments of the economy, for example, mechanical power for agriculture, textile, transport, and other industries.
- Access to modern energy for public services, for example, electricity for health facilities, schools, and street lighting.
- Electricity access is multidimensional, involving dimensions such as affordability, reliability, and safety, among others.

All of these elements are crucial to economic and social development, as are a number of related issues that are sometimes referred to collectively as “quality of supply,” such as technical availability, adequacy, reliability, convenience, safety, and affordability (IEA 2020).

Cooling is Critical for Off-Grid Rural Communities

Sustainable Energy for All (SEforALL) estimated that 306 million poor people living in rural areas in 77 countries assessed by the Chilling Prospects analysis are at high health and safety risk due to a lack of access to cooling, of which an estimated 52 percent are women (SEforALL 2023). This represents approximately 27 percent of all those who are living in high-risk areas worldwide.[1] SEforALL defines these populations as facing risks that include lack of access to electricity services and income below US$2.15 per day. Since their incomes are below the poverty line, they will need significant support to gain access to electricity or cooling services. A share of the 2.9 billion urban and rural people that SEforALL estimates as being exposed medium risks due to lack of cooling,[2] will also be found in off-grid areas; they have some access to electricity and incomes of less than US$10 per day but nevertheless require support to obtain greater access to cooling services.

Lack of cooling creates challenges such as difficulty coping with extreme heat—to which half of the global population was exposed for at least 30 days in 2023 (Climate Central 2023)—and heat stress in homes, schools, and small businesses. Lack of cooling also leads to loss of economic opportunities in rural off-grid areas, because of the shorter life of perishable produce and the inability to transform them into higher value commodities—challenges that access to cooling can address. Lack of cooling thus hampers economic development in high-temperature rural areas and climate resilience, as well as efforts to meet other basic needs, due to insufficient electricity access to reliable power. The lack of electricity makes it difficult to use fans (let alone an air conditioner) or refrigerators, to operate cold chains needed to preserve vaccines, or protect workers and produce in the agricultural or fishing, livestock, and dairy sectors. Further, rural residents typically have lower incomes, lower ability to pay for sustainable solutions, and fewer public or communal resources to invest in sustainable cooling than urban residents (AfDB, OECD, and UNECA 2022).

While passive measures can provide some measure of cooling, most cooling services require energy to power appliances. However, despite global efforts toward universal electricity access, 675 million people worldwide lacked access to electricity in 2021 (of which nearly 600 million were in Sub-Saharan Africa); 80 percent of which were rural residents (Galal 2023).

Distributed renewable energy technologies for off-grid use, including solar home systems and other stand-alone solar systems, are increasingly economically viable options to achieve sustainable access to energy beyond peri-urban settings. The number of people accessing electricity worldwide using solar energy kits alone is estimated to have grown from 420 million in 2019 to 490 million by the end of 2021. While some of them live in urban and peri-urban areas with poor grid service, the majority live in off-grid areas. Off-grid solar technologies are expected to be the least-cost solution for 41 percent of new household connections between 2020 and 2030 (Lighting Global/ESMAP et al. 2022b). At the same time, off-grid solar systems used in combination with efficient off-grid cooling equipment that minimizes the use of HFC refrigerants (where needed) offers a real opportunity to increase access to sustainable cooling without causing a rapid increase in GHG emissions.

While urbanization trends continue, it is nevertheless projected that in 2050, over 3 billion people will be rural inhabitants, including 1.58 billion living in the nine so-called critical-heat-risk countries of Bangladesh, Brazil, China, India, Indonesia, Mozambique, Nigeria, Pakistan, and Sudan (SEforALL 2018).[3] The proportion of rural residents above 65 years of age—a key risk factor for heat-related stress—will also increase to 22.7 percent by 2100 (from 8.3 percent in 2015) (FAO 2017). SEforALL analysis suggests that the number of rural residents at high risk by can be reduced by over 80 percent by achieving full electrification and ending extreme poverty, in line with the Sustainable Development Agenda (SEforALL 2023).

The needs for cooling services in rural communities fall under three main categories: (1) human safety and comfort; (2) agriculture, food security, and nutrition; and (3) health care.

Human safety and comfort. The human body has limited resistance to heat, and temperatures above a certain threshold affect productivity and physiological and psychological health. Heat stress can also hinder economic and social development and can even be a driver for migration within and between countries (ILO 2019). In rural settings, outdoor workers, farmers, pregnant women, children, the elderly, and those with weakened immune systems are at increased risk of heat stress. They represent the majority of the rural population. Cooling needs in rural areas are typically addressed with passive solutions such as increasing air circulation, shading, and measures to reduce heat penetration through roofs and walls. Fans are also used as an active cooling strategy, although they are only purchased by a small proportion of rural off-grid households.[4]

Agriculture, food security, and nutrition. The vast majority of rural populations engage in some form of subsistence farming, herding, or fishing, which can be collectively categorized as agriculture. However, every year, large quantities of food produced are wasted along the production value chain, including at the post-harvest stage. United Nations Environment Programme (UNEP) estimates that 931 million tons are wasted every year (2019 data), representing 17 percent of overall global production. This waste represents not only a missed opportunity for food security, it also hinders farmers' economic potential to earn a decent livelihood (UNEP 2021). It also risks exacerbating gender inequalities as women represent up to 50 percent of agricultural workers, and post-harvest activities are often part of traditional women's household responsibilities (SEforALL 2023). One important solution to reducing food waste and ensuring better livelihoods through improved economic opportunities, is to expand access to cold facilities that extend the life of produce through efficient storage and transport. In many developing countries, farmers lack access to local cold storage facilities or an unbroken cold chain that would prolong the life of produce and enable it to reach markets further afield in good quality. Farmers thus have limited ability to command higher prices for their produce. It is estimated that this lack of access can reduce farmers' incomes by at least 15 percent (Castañeda et al. 2016).

Climate change is making the situation worse. Already in 2020, 98 million more people than in the previous years were affected by food insecurity because of the effects of extreme heat and drought (The Lancet 2022). Women are more likely than men to experience moderate or severe food insecurity (FAO 2022). The Intergovernmental Panel on Climate Change's (IPCC's) Sixth Assessment Report (AR6) warns that global warming of 1.5–2°C would trigger more frequent, intense, and severe droughts and heat waves in the absence of or limited climate adaptation. With warming above 2°C in the medium term, food security and nutritional risks will be exacerbated in Sub-Saharan Africa, South Asia, Central and South America, and small island states (IPCC 2022).

Health Care. Access to cooling is vital to maintain the efficacy of vaccines and other medications, blood product stability, operation of critical medical equipment and processes and for thermal comfort in hospitals and health centers in rural areas. While passive cooling can deliver some benefits, sufficient reliable electricity is needed to power cold chains for storage and transport, and to operate lighting, communication, and space cooling equipment, among others. Yet, an estimated 1 billion people in low- and lower-middle-income countries are served by health care facilities without reliable electricity (WHO et al. 2023). The COVID-19 pandemic has highlighted the importance of a massive and equitable expansion of sustainable vaccine cold chains for routine vaccinations as well as possible future pandemics. According to World Health Organization (WHO) estimates, lack of adequate cold storage and refrigerated transport contributed to over 1.5 million vaccine-preventable deaths every year before the pandemic. Meanwhile, a 2020 DHL study estimated that all African states except South Africa, Rwanda, Côte d'Ivoire, and Botswana had limited feasibility (low to medium) for in-country COVID-19 cold chains at conventional temperatures of 2–8° (DHL 2020).

Gender affects access to cooling as well as many other aspects of life. Women and girls face specific challenges in accessing and benefiting from cooling services that meet the three types of cooling needs. These difficulties stem from factors such as poverty, household and workplace dynamics, and access to health care and nutrition. Policies, initiatives, and investments to increase access to essential cooling services should therefore include gender considerations to avoid perpetuating existing disparities (SEforALL 2021c).

Impact of Global Warming on Rural Communities

Climate change is further escalating the largely unmet demand for cooling services in rural areas. The increasing scale of heat waves and instability of weather mean that cooling is shifting from an issue of human comfort to one of human safety. While there are no data on rural off-grid areas, recent data show 356,000 deaths due to extreme heat in 2019 alone—and casualties are likely to increase as temperatures continue to rise, posing significant risks for vulnerable groups.[5] Rising global temperatures will also exacerbate already significant food and agricultural productivity losses and increase the need for refrigeration and cold chains in rural off-grid areas. Climate change also exacerbates risks for rural farmers by increasing the likelihood of major food production regions potentially suffering simultaneous low yields (Kornhuber et al. 2023).

Addressing cooling needs presents different challenges in rural compared with urban areas. This difference stems not only from the factors mentioned earlier, but also from the nature of cooling needs in farming-related economic activities such as livestock rearing, dairy production, crop production, and post-harvest processing and storage of produce. During Kenya's 2022 drought, for example, cooling on farms could have at least partially mitigated issues related to the loss of livestock and crops, which affected millions of smallholder farmers (Mokku 2023).

Increased heat stress and a lack of access to cooling affect critical growth- and income-boosting sectors of the rural economy, notably, agriculture and construction. The International Labour Organization predicts that, in 2030, 60 percent of the global heat-stress-related loss of working time will be in agriculture, and that Africa's agriculture sector will suffer 89 percent productivity loss due to heat. Among the regions with the most acute lack of cooling and electricity access, heat stress will cause 92 percent loss of total working time in agriculture in Central and East Africa. In the Pacific Islands, this time loss will be 87 percent, and 75 percent in West Africa (Saget 2023). The construction sector, another important employer in rural areas, is also projected to see 19 percent working time reduction.

Climate change also exposes rural residents to other risks, for example, due to poor-quality housing; a lack of vegetation cover; and a general lack of access to economic, informational, and social resources that would help them access cooling and improve their adaptive capacity to climate change impacts. In 2023, temperatures above 45°C in rural areas of North Africa and Pakistan, among others, exposed residents to potentially deadly threats from extreme heat (Al Jazeera 2023; Logan 2023). This was partly because rural communities typically lack the communal cooling facilities or infrastructure more likely to exist in cities. Rural economies also rely by definition more on outdoor activities than urban economies. This exposes rural dwellers to climate hardships, without alternatives, often under conditions of increasing temperature.

Expanding access to cooling in rural areas affected by poverty, low population density, and low electricity access will require different approaches than for denser, higher-income urban areas. Not all potentially innovative and sustainable cooling technologies developed for higher income or urban contexts will be viable in rural areas of low- and middle-income countries. Care must be taken to either match technologies and business models to local conditions or develop suitable technologies and business models. The challenges are not only technical, but also cultural, making it essential to engage local populations from the outset to define in a participative manner the solutions that are best suited for local conditions.

Further, socioeconomics-, human-capacity-, and gender-based considerations must differ between interventions for rural and urban areas. Interventions for rural areas should consider, for example, the availability of basic infrastructure and services, including electricity; the availability of a technically qualified workforce to operate, sell, service, and maintain cooling equipment; as well as factors of emigration and vulnerable, climate-sensitive livelihoods. In developing countries, poverty rates are typically higher among female- than male-led rural households, and women have lower workforce participation rates and lower access to social infrastructure and development schemes in rural settings (ADB 2019). Rural women working in the agricultural sector can be particularly vulnerable to heat due to a lack of formality in employment structures.

The Off-Grid Energy Access Challenges for Cooling

While passive cooling measures can mitigate the need for cooling services and equipment, removing heat and/or producing cold through active cooling requires energy. Sufficient reliable and sustainable energy must first be available at an affordable cost, for the target population to be able to use cooling appliances and achieve the desired level of cooling. Currently, electricity meeting the above criteria is accessible only to a fraction of the potential users of cooling appliances in these off-grid areas.

Achieving Sustainable Development Goal indicator 7.1.1 (universal electrification) for a household requires only basic electricity access—sufficient to power a bundle of services, including minimal lighting for a few rooms and mobile phone charging. When these goals were created, access to at least modern clean lighting was agreed as a minimum requirement for defining off-grid household electricity access—which was only made possible by revolutions in lighting and battery technology. This report now makes the case for accessing modern cooling services being accepted in a similar way as an essential element of electricity access (see also SEforALL and CLASP 2021). As electricity quality improves, and electricity becomes more reliable, rural populations with growing income can be expected to access more advanced solutions such as larger, more powerful fans, refrigerators/freezers, or evaporative coolers. Planning for cooling demand and electricity therefore requires an integrated view of electricity access levels, the efficiency and affordability of active cooling solutions in off-grid settings, and the need for sustainable energy and efficient cooling solutions to mitigate climate change.

Most of the existing technological solutions for cooling were developed for industrial applications or urban environments in emerging markets. Clearly, the majority of these appliances' key design parameters, as well as the business models, financing methods, and policies used to promote them, are likely to be different from those needed to suit rural contexts in emerging markets.

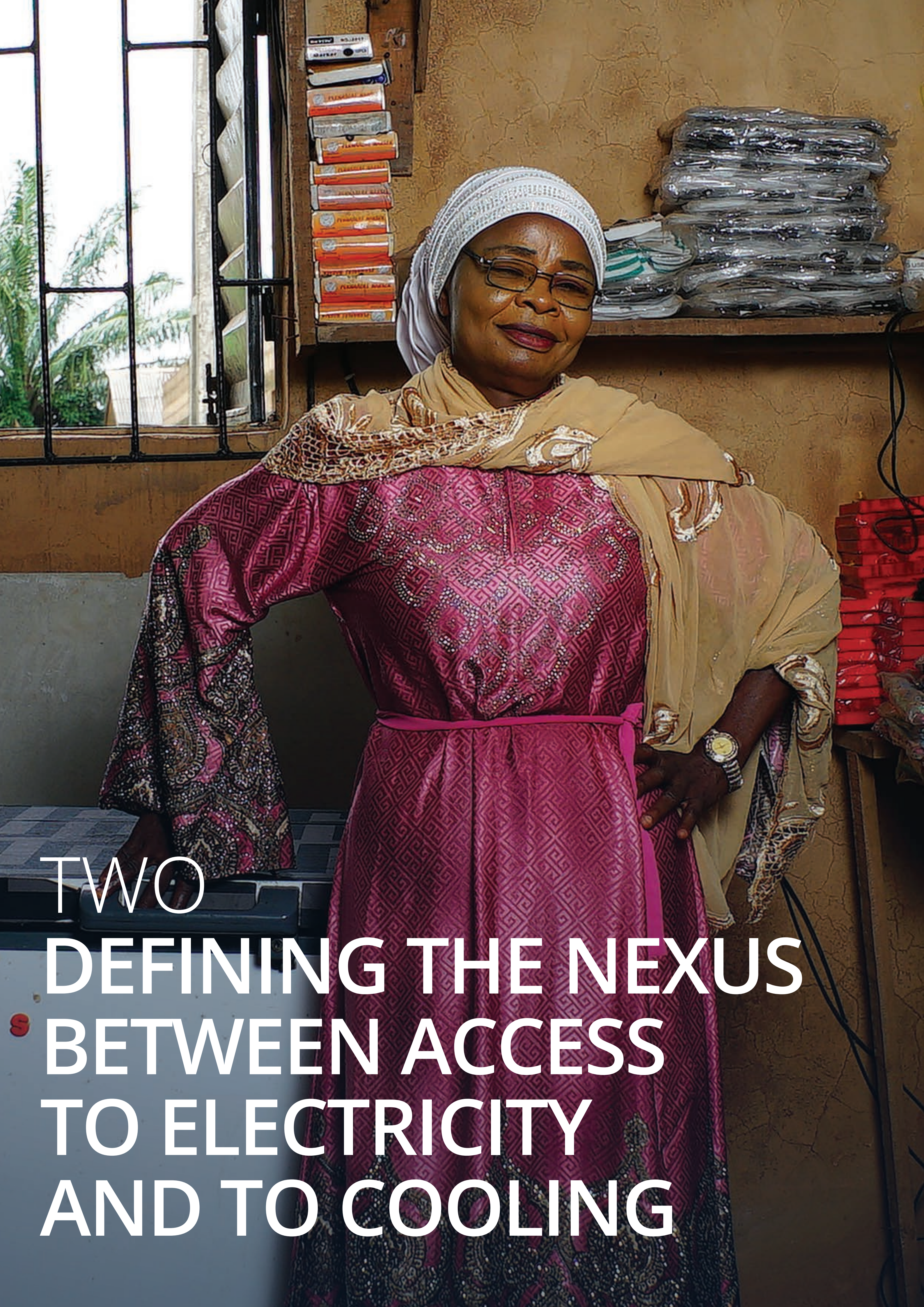
This report focuses on electricity provision in off-grid areas via solar-powered stand-alone units, which predominantly produce direct current (DC) electricity, which is best suited for meeting the relatively low power requirements of the vast majority of rural households and micro-enterprises in these off-grid areas, besides meeting the agricultural or health care cooling needs. Although the number of and the energy capacity of the supported appliances is rather low (see Box 1.1.), they are beginning to meet the domestic and light enterprise needs of typical users.

For the provision of cooling services on a large scale to be sustainable, the energy sources powering any application should be carbon neutral and the refrigerants or insulation used in the appliances themselves should have low global warming potential. For off-grid areas, this mostly means using solar electric or solar thermal (for absorption refrigeration appliances) power for niche appliances that are powered by, for example, DC motors. Appliances of this type are typically more expensive and supplied by fewer manufacturers than appliances driven by alternating current (AC), which are powered through the grid and are already produced for mass global markets. The financial, technical, and commercial implications and challenges in supporting the expansion of DC-powered cooling appliances for off-grid (typically rural) markets, which are the subject of this report, are different from those for appliances to be used by rural communities that can access power from a grid or mini grids.

Access to sustainable cooling solutions in off-grid settings hinges on the availability and affordability of the solutions themselves and the availability of reliable, affordable, and sustainable electricity. This applies across the three areas of cooling demand that are the focus of this report—cooling for human safety and comfort, agriculture and food, and health care.

Endnotes

1. Approximately 1.121 billion people are at high risk due to a lack of access to cooling in high-risk countries, of which 815 million are in urban areas and 306 million are in rural areas (SEforALL 2023).
2. The populations at medium and low risks due to lack of cooling are not disaggregated between urban and rural populations in the cited SEforALL report.
3. These countries have the highest number of people considered to be at high risk due to a lack of access to cooling—divided between the rural poor and the urban poor.
4. A leading technical solution to heat stress indoors is air-conditioning, which is common in urban areas but not rural areas and practically absent in remote off-grid areas, due to lack of electricity and affordability.
5. At 2–3°C of warming, 16 times as many people would be exposed to heat waves, with even greater deaths (SEforALL 2022a).



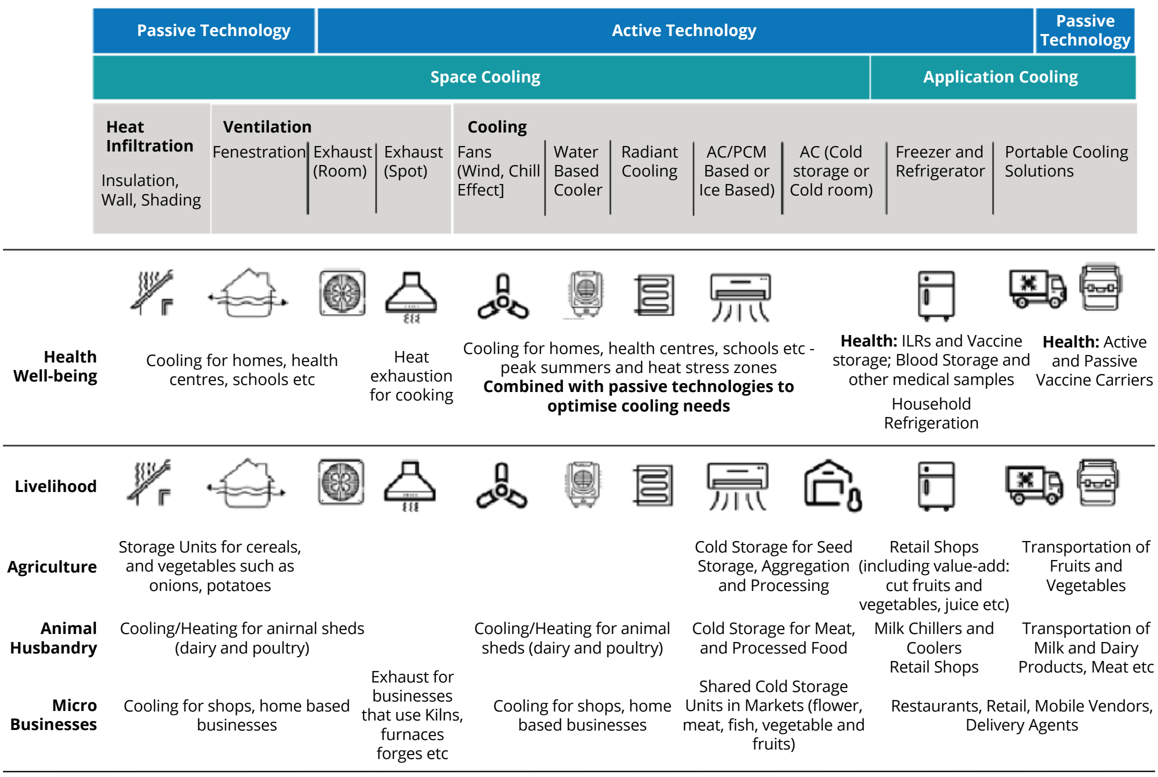
TWO
DEFINING THE NEXUS BETWEEN ACCESS TO ELECTRICITY AND TO COOLING

Considerable efforts have been made since 2010 toward reaching and tracking Sustainable Development Goal 7: "Ensure access to affordable, reliable, sustainable and modern energy for all." Further analysis is needed to better understand the cooling solutions that can be made accessible to populations at risk, and their impact on reducing cooling access gaps. As people gain higher quality electricity access and their incomes grow, more of them can be expected to own cooling solutions such as fans and refrigerators. Accelerating the uptake of sustainable cooling solutions among those with limited or unreliable access to electricity will require the availability of efficient solutions that can be powered at lower tiers of energy access and are affordable. At the same time, the desire for cooling services can drive the demand for access to the initial tier of energy or an increased level of electricity services, in off-grid areas where individual households or farmers or groups of farmers can purchase and operate energy and cooling equipment powered by off-grid solar solutions.

There are a range of passive cooling measures/technologies (e.g., ventilation), as well as active cooling technologies that require energy (efficient fans, refrigerators), as shown in Figure 2.1. However, poverty poses a major obstacle to the changes in building structure or landscaping required for implementing passive technologies, as well as to the purchase and operation of stand-alone energy systems and cooling equipment. Poverty is also a barrier to energy access.

FIGURE 2.1

Cooling Technology Types and Their Applications



Source: SELCO Foundation 2023.

Note: AC = air conditioner; ILR = ice-lined refrigerator; PCM = phase-change material.

Where cooling access can support economic activities through productive uses (e.g., refrigeration in agriculture cold chains), the additional revenues generated can help cover the costs of accessing electricity as well as cooling, especially under some form of "energy as a service," lease to own, or pay-as-you-go (PAYG) model.

The first section of this chapter looks at the significant benefits that can be generated by promoting improvements in off-grid areas at the nexus between access to cooling and electricity, with energy access increasing opportunities for active cooling and cooling access increasing opportunities for energy access and, in some cases, making it more affordable. Section 2.2 provides an initial overview of issues that hinder access to grid electricity in rural areas, and indicates that off-grid solar systems are expected to play a significant role. This is followed by a discussion of the status of electricity access and cooling access in rural off-grid areas and the challenges to expanding cooling services.

Benefits of the Cooling Access–Electricity Access Nexus

The nexus between access to electricity and access to sustainable cooling represents a unique opportunity for governments, development partners, and the private sector to support progress on the Sustainable Development Goals and the just and inclusive energy transitions called for by the Paris Agreement. Electricity access can help meet critical cooling needs (e.g., by powering life-saving cooling during heat waves, by powering refrigerators, which preserve food quality and nutrition and could support livelihoods, and by maintaining refrigerators' temperature for storing critical vaccines). In rural farming communities, for example, access to cooling can boost farm productivity and income (USAID 2022) and potentially provide additional energy demand to support stand-alone electricity access. Affordable refrigeration, for both commercial and household use, is among the top services in demand in developing rural areas. It is one of the technology breakthroughs with the highest potential to boost the rural electricity demand (Efficiency for Access 2020a). Finally, gender-responsive interventions will ensure that women and men benefit equally from access to electricity and access to cooling. Table 2.1 outlines the mutually beneficial relationship between access to energy and cooling.

TABLE 2.1

The Cooling Access–Electricity Access Nexus, and Adaptation

COOLING ACCESS–ELECTRICITY ACCESS NEXUS	AGRICULTURE, FOOD SECURITY, AND NUTRITION	HUMAN SAFETY AND COMFORT	HEALTH CARE
Cooling (adaptation) benefits due to electricity access	Households or communities can store more nutritious food longer. Cold storage prolongs the life of the produce and products of farmers, fishermen, or herdsmen and enables them to reach markets further afield in better condition and obtain higher prices in new or existing markets. Food waste and methane emissions from decomposing food are avoided.	Ability to reliably power a fan or more powerful cooling appliances during a heat wave. Productivity improvement in the workplace and in classrooms.	Comfort cooling in rural health clinics. Cold chains preserve the efficacy of vaccines and other medical products.
Electricity access benefits due to cooling	The desire to power cooling appliances drives the demand for electricity access. Productive cooling services help pay for stand-alone off-grid power systems, for example, solar. Methane emissions from decomposing food are avoided.	Off-grid cooling appliances drive a demand for greater electricity access. Passive and efficient active off-grid cooling accelerate access to higher levels of household electricity services.	Improved efficiency and performance of cooling appliances frees up electricity to support expanded health care operations and services. This can also provide additional load, which may make some electricity access solutions more economic.

Examining the overlap of countries where increasing rural access to (1) electricity and (2) cooling would have a significant impact (Figure 2.2) reveals 19 priority countries. Combined, these countries are home to at least 248 million rural residents whose demand for electricity and cooling is likely to go unmet without combined energy and cooling access interventions. The rural populations of these 19 countries represent over 50 percent of the world's total unelectrified rural population and 81 percent of the rural low-income population at high risk of health impacts due to lack of access to cooling.

There are significant opportunities at the nexus between access to electricity and cooling in these countries with electricity access deficits, high cooling risks, or both. These include opportunities for substitutions, bundling, and increasing the market demand for both cooling and energy access solutions. Specific examples include:

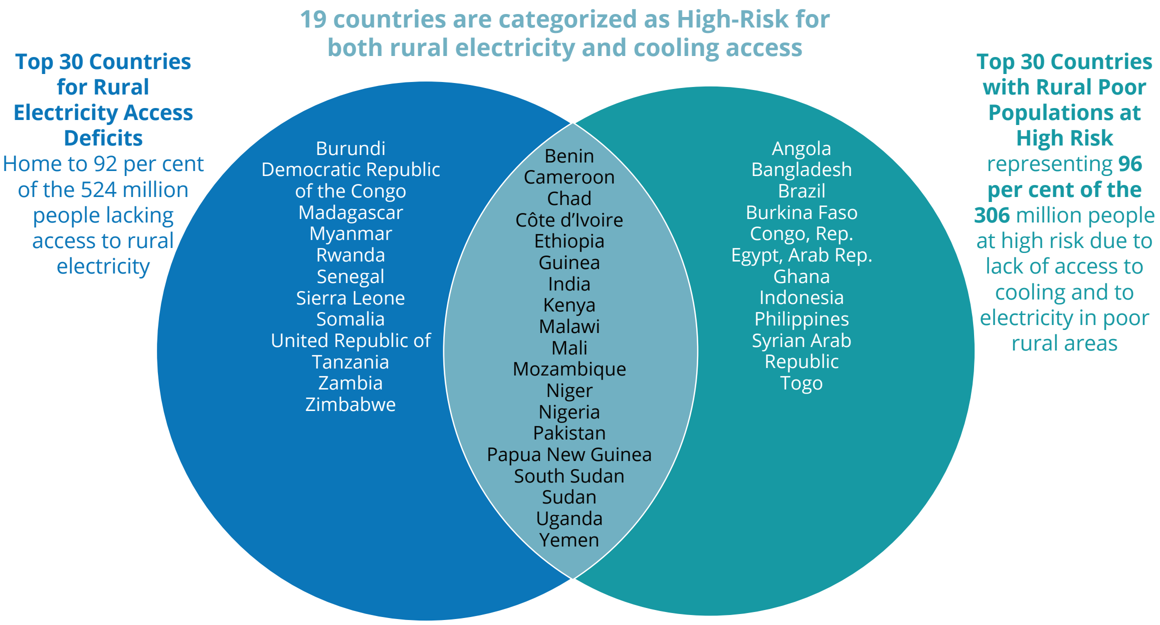
- In Nigeria, fossil-fuel-powered generators, typically used to power refrigerators, are being replaced by solar units. Also, in agricultural cold chains, where power backup is typically provided by generators, solar power paired with thermal storage (using "ice batteries") often proves a viable replacement. In vaccine cold chains, solar thermal refrigerators have already replaced kerosene- or generator-powered solutions (Lighting Global/ESMAP et al. 2022a).
- A World-Bank-funded energy access program in Pakistan's Sindh province found that fans had to be added to household solar and lighting kits since this cooling appliance

was deemed essential for the cost of solar home systems (SHSs) to be justifiable for the targeted unelectrified communities (see Appendix A, Case 4).

- More broadly, the fan sales trends evidenced in the Global Off-Grid Lighting Association (GOGLA) sales data collection exercise show that technology efficiency and cost improvements over recent years have resulted in a growing trend of expanded demand for fans and their bundling with SHSs in Sub-Saharan Africa.

FIGURE 2.2

The Nexus of High-Risk Countries for Rural Access to Electricity and Cooling



Rural Off-Grid Electrification and the Challenges Ahead

As noted in earlier sections, despite global efforts toward universal electricity access, 675 million people worldwide remained without electricity at the end of 2021 (of whom nearly 600 million were in Sub-Saharan Africa) about 80 percent of these or 540 million people were rural residents (Galal 2023). While electrification improved significantly over 2010–20, progress in recent years has been slowed down by complexities associated with last-mile connectivity. A current trend projection and the scenario analysis of the International Energy Agency (IEA) show that the world is *not* on track to achieve universal electricity access by 2030. Without additional efforts and measures, some 660 million people—560 million in Sub-Saharan Africa and 70 million in Developing Asia—will remain unserved in 2030 (IEA et al. 2023).

Achieving universal electricity access by 2030 requires that annual growth in electrification be ramped up to 1 percentage point per year from 2021 on, instead of the 0.6 percentage point annual pace over 2019–21, through investments and policy support. According to

IEA's Net Zero by 2050 Scenario, annual investment of US$30 billion will be required to achieve universal access to electricity by 2030 (IEA et al. 2023).

The number of people obtaining electricity from such systems worldwide grew from 420 million in 2019 to 493 million by the end of 2021, with more people gaining higher "Tier 2" levels of access. Based on current trends and assuming development community support, the industry estimates that, by 2030, it can serve an additional 131 million people for a total of 624 million people accessing electricity at a minimum of Tier 1 through off-grid solar. This would help but would meet only a part of the need to meet Sustainable Development Goal (SDG) 7. If additional support were provided to accelerate efforts, the industry estimates that off-grid solar would be the least-cost solution to provide Tier 1 electrification to a further 464 million additional people (rather than 131 million), representing 41 percent of new household connections between 2020 and 2030 (Lighting Global/ESMAP et al. 2022b). Further, there is a significant market to upgrade existing users to higher service levels (Lighting Global/ESMAP et al. 2022a) that would enable using cooling and other appliances. Off-grid solar solutions hold considerable potential for closing the access gap in remote and rural areas of Sub-Saharan Africa, where weak utility creditworthiness and other challenges such as the absence of infrastructure and low population densities have impeded progress in grid electrification (ESMAP 2022).

The off-grid rural population served by these off-grid solar systems, estimated at 493 million people and potentially reaching 624 million by 2030, would be the main target population for the off-grid cooling interventions discussed in this report.[1] To achieve the off-grid solar sector's potential, interventions are needed to address several remaining barriers to off-grid electricity access. Action is needed to address the affordability gap of vulnerable low-income consumers as well as constrained company margins due to the high-costs of market development in new areas. In addition, market-specific barriers related to product and installation quality control and lack of consumer awareness will need to be addressed.

Rural Cooling and the Challenges Ahead

The Low Energy Inclusive Appliances program and the Efficiency for Access, along with other parties have undertaken work to characterize and quantify the state of off-grid appliance markets and the barriers to technology adoption in off-grid and weak-grid settings, including off-grid cooling products and services. When planning for new interventions to support off-grid access for cooling, consideration must be given to the prospect of grid connection; up-front costs for energy and cooling equipment, installation and maintenance; target energy demand and the price per unit of energy. Increasing the efficiency of off-grid cooling appliances can boost the sales of off-grid systems as these appliances can be powered by lower-cost, smaller solar systems than needed for less efficient appliances. This can substantially reduce electricity bills or the cost of solar power systems. However, up-front investment and life-cycle costs can hinder the purchase of more expensive appliances, which typically represent a significant proportion of a household's or businesses' income. For example, in 2019, entry-level off-grid refrigerators were sold for up to US$900 in various Sub-Saharan African markets (Efficiency for

Access 2019c). Even less costly technologies prove inaccessible: in India, a solar home system kit with a fan can cost approximately US$80—more than 50 percent of an average consumer's monthly income (Efficiency for Access 2022a).

For agricultural cold chains, consumer demand is beginning to emerge based on the benefits to businesses and farmers, fisherfolk, or herders from using cooling, refrigeration and freezing to preserve their production (Efficiency for Access 2020a). For off-grid households, the Efficiency for Access projects a doubling of off-grid fan and refrigerator sales—from US$12.6 billion globally in 2018 (Efficiency for Access 2019a) to just over US$25 billion in 2030 (Efficiency for Access 2019c). Given this rapid growth, sustainable cooling solutions must be designed for maximum efficiency, to provide maximum cooling with minimum energy consumption. This will prevent overloading existing systems and overdesign of future systems. This must, however, consider the boundaries of prices that the targeted customers are willing and able to pay

The dangers of using unsustainable technology to meet the growing cooling need in an overheating world have been well documented. Evidence from China suggests that between 1990 and 2016, the demand for air-conditioning and refrigeration drove up rural household electricity consumption from 51.3 billion kilowatt-hours in 1993 to 131 billion kilowatt-hours in 2002. Rural ownership of refrigerators grew from only 1.2 rural households per 100 in 1990 to 17.8 in 2004, whereas air conditioner ownership grew from effectively zero to 4.7 households per 100 over the same period (Jiahua et al. 2006). To obtain benefits from increased access to sustainable cooling while avoiding growth in greenhouse gas (GHG) emissions from increased electricity demand for cooling appliances, programs to expand access to off-grid electricity and cooling must use only renewable energy sources such as solar, as well as efficient electricity and cooling equipment that minimizes use of hydrofluorocarbon (HFC) refrigerants if needed.

As rural communities in high-temperature climates gain electricity access, similar demand growth may be expected. Unless this demand is met with sustainable solutions, emissions can be expected to grow and slow down efforts to mitigate climate change impacts. This is why efforts to address cooling needs for all must include as key aspects ensuring the energy efficiency of cooling appliances and minimizing the use of HFCs for refrigeration and air-conditioning appliances. Where rural communities are unlikely to have grid access for a long time, this constraint can be turned into a driver of innovation in passive as well as low-power, affordable active cooling technologies for use in off-grid settings. These technologies may then also offer innovations that support higher efficiency and promote the use of clean-energy-based power generation or storage mediums for grid-connected use.

While awareness of and innovation in rural access to cooling is growing, a number of growth barriers remain:

- **Insufficient awareness and attention to sustainable cooling, including passive and natural cooling solutions.** Much of this report is focused on active cooling solutions that require energy for power. Focus should also be given to passive and natural solutions to minimize cooling loads using active technology. This requires greater awareness of and focus on links to innovation in construction.
- **Lack of reliable market data.** Lack of reliable market data (such as projected growth of demand by market segments, clarity on risks, information on sources of finance, e.g., local banks and microfinance or agricultural finance institutions and funding gaps for sustainable

cooling) poses challenges to developing strong business cases, to demonstrate the importance of this topic to policymakers and attract private entrepreneurs.

- **Efficient cooling technologies unaffordable for lower income households.** Increased investment is needed to drive innovation in both passive and active cooling solutions, always with an intention of producing suitable equipment at scale and ensuring affordability for the predominantly low-income consumers rural areas.
- **Absence of support for productive uses weakens the development impact of access to cooling and energy in rural areas.** Access to productive use cooling applications could support new income generation activities for rural households and businesses. This in turn helps offset electricity access expenses. Despite this potential, business cases for productive uses of electricity and cooling are often not well developed, in part because other requirements such as transport to markets, proper packaging, and access to financing remain elusive in rural areas. Given the relatively high cost of off-grid cooling equipment for productive uses due to the lack of scale, the cost remains a barrier
- **Lack of quality assurance programs and HFC phasedown plans for off-grid cooling appliances.** Such quality assurance programs include the development and adoption of quality standards for off-grid cooling products, supplier-backed warranties, and compliance mechanisms. The off-grid cooling appliance market remains nascent and disorganized. The nascency of this market means standards developed specifically for off-grid cooling products are largely nonexistent, except for a few sectors. Examples of such sectors include health care (e.g., World Health Organization standards for off-grid vaccine refrigerators). Similarly, there is a lack of HFC phasedown plans to help reduce GHG emissions from off-grid cooling appliances.
- **Lack of a skilled workforce to install and maintain cooling equipment and facilities.** For domestic and small-scale commercial cooling appliances like off-grid fans, refrigerators and freezers, local technicians, spare parts and refrigerants are needed in off-grid areas for appliance maintenance. For the larger cooling facilities, like walk-in cold rooms, skilled refrigeration/HVAC engineers are needed to install and design the facilities while skilled technicians will be needed in off-grid rural areas to maintain them. Technical capacity is needed to manipulate refrigerants safely and efficiently, and also to design and install the power systems for these cooling facilities.
- **Lack of institutional coordination and collaboration.** Due to the multisectoral nature of cooling the lack of intersectoral cooperation and coordination among government institutions and other stakeholders working in sectors such as agriculture, energy, health care, and the cross-cutting areas of environment and climate change hinders the advancement of the cooling agenda.

Endnote

1. To give an idea of the current scale and level of service of solar system and appliance sales, GOGLA estimates worldwide sales in 2022 at 9.5 million solar energy kits, of which 62 percent were lanterns, 20 percent were multi light systems and 18 percent were solar home systems. Of the total sold, 63 percent were sold on a cash basis, the remainder using Pay-as-you-go (PAYG). In 2022, sales of off-grid solar fans worldwide were estimated at 1.08 million units and off-grid solar refrigerator sales were estimated at 7,400 units (GOGLA n.d.).

THREE
CURRENT STATE OF OFF-GRID COOLING AND ENERGY ACCESS

Provision of access to cooling services in rural areas clearly needs to improve, to maximize the development impact of electricity access and foster a just and inclusive energy transition. As noted earlier, in Chapter 1.1, lack of cooling access exposed an estimated 306 million rural residents living in poverty worldwide to high health and productivity risks in 2023 (SEforALL 2023), the risk factors including no electricity access and incomes below the poverty line of US$2.15 per day. At the same time, 524 million rural residents worldwide were still without electricity in 2021 (IEA et al. 2023). Integrated expansion of electricity and cooling access can leverage the synergies between these two services and foster economically viable solutions, which will maximize benefits for populations. Given the links between cooling and a range of Sustainable Development Goals, a successful strategy to address the cooling access–electricity access nexus can yield diverse potential benefits related to poverty, health, and nutrition (Peters 2017).

This chapter will discuss the off-grid cooling technologies that are available for use with the stand-alone technologies for electricity provision in areas without main or mini grid service. It will also look at the trends in the development of and access to such technologies. The chapter will begin with an overview of off-grid cooling technologies that includes a subsection on general trends and innovations, followed by separate subsections that discuss off-grid technologies for space cooling, refrigeration, and cold chains (e.g., walk-in cold rooms). This is followed by a section that relates off-grid cooling technologies to the Multi-Tier Framework (MTF) for electricity access, showing that energy efficiency improvements have made cooling services available at lower tiers of access and a section that discusses the affordability of off-grid cooling.

An Overview of Off-Grid Cooling Technologies

Sustainable cooling solutions cover a range of materials and products, which include (1) those that do not require energy or refrigerants to function (i.e., nature based and passive technology solutions) and (2) those that require electricity and, for refrigeration, climate friendly refrigerants used efficiently (i.e., active technology solutions). The passive solutions include cool roofs, green roofs, vegetation, shading, and ventilation. The active technology solutions, too, are diverse, encompassing small devices (e.g., handheld, table-top, or free-standing fans), intermediate sized devices (e.g., refrigerators, freezers and walk in cold rooms), and large systems (e.g., district cooling systems in urban areas), covering traditional low-tech to modern hi-tech solutions. This section will focus on the most appropriate technologies for off-grid rural consumers, which must be affordable and highly efficient, deliver high performance, and be easily repaired, with access to maintenance and spare parts.

Trends and Innovations in Off-Grid Cooling Technologies

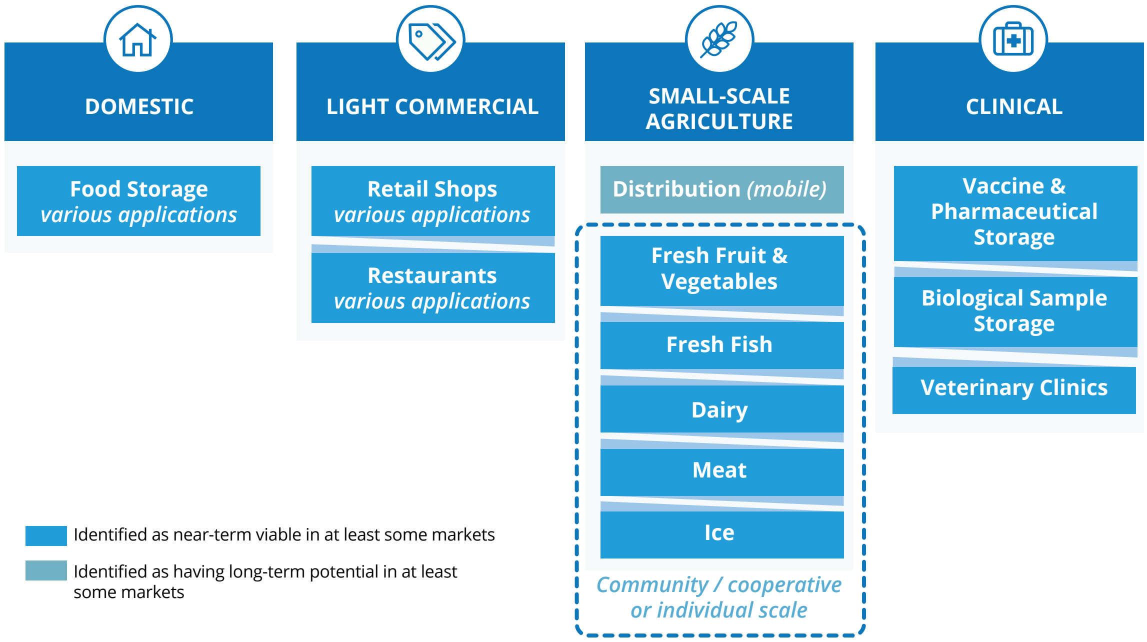
There have been continuous innovations in technologies supporting sustainable cooling in rural settings.[1] The Efficiency for Access Initiative provides significant resources for staying abreast of the latest solutions (e.g., Efficiency for Access 2021e). The off-grid solar sector also witnessed tremendous innovation over the past decade that has made systems more energy efficient, improved their performance, and increased their affordability for off-grid communities. In recent years, notable innovation has also been seen in the productive use of renewable energy (PURE), especially for increasing agricultural productivity through, for example, utilizing cold storage equipment and off-grid cold chains for produce. At the component level, technological advances in solar photovoltaic (PV) cells have increased their capacity to harvest 30 percent more solar energy (by one estimate in Dada and Popoola [2023]), significantly reducing the per unit energy cost (infoDev 2017). Reduction in use of hydrofluorocarbons is increasingly being adopted under the Kigali Protocol to further mitigate greenhouse gas emissions. Meanwhile, an off-grid refrigeration system's cost predominantly stems from the combination of the battery, the solar panel, the charge controller, shipping, duties, and taxes, regardless of geography or model (Efficiency for Access 2020b). Since costs are determined by such a wide array of factors, a holistic approach of policy and supply chain development is needed to dramatically improve affordability. Efficiency and performance improvement are essential, but alone will not be sufficient.

Lessons learned and best practices in the off-grid cooling sector are only just emerging and are yet to be widely incorporated into the operations supporting this sector. Globally, only a handful of specialized companies, institutions, and development partners have expertise in sustainable off-grid cooling solutions.

Solar cooling, widely regarded as an emerging area only a few years ago, has many elements that can now be considered near to market, or market ready, thanks to increasing research and development efforts spurred by a higher demand for vaccine storage and strong potential for off-grid productive use applications. Off-grid fans are now available from solar systems dealers in many areas, although they are owned by only a small proportion of households in rural off-grid areas. A wide variety of fridges, freezers, and combined fridge-freezers designed for use off-grid in lower-middle-income countries are now available on the market spanning Sub-Saharan Africa, Asia, and beyond; but sales remain in the thousands worldwide, indicating limited adoption (Efficiency for Access 2021f.). Product diversity is, however, sufficient to suit a range of distinct use cases. Donor-funded development and trials combined with actual commercial demand are driving greater efficiency, higher performance, and lower costs (see Figure 3.1). For example, the VeraSol program has developed testing and quality standards for stand-alone solar PV systems and off-grid appliances. Highly effective models have been identified, which utilize both alternating current (AC) and direct current (DC) power systems, with solar-battery-powered and solar direct drive designs (Lighting Global and ESMAP 2022).

FIGURE 3.1

Use Segmentation for Off-Grid Solar Refrigeration Systems



Source: Efficiency for Access 2020b.

Examples of larger scale commercial off-grid cooling beyond its use in the health care sector (in vaccine cold chains) consist largely of pilot innovations and early-stage start-ups clustered in a handful of countries (e.g., India, Nigeria, Kenya, Rwanda). Of these countries, India is quickly progressing toward a mature market with more units deployed than in all of Sub-Saharan Africa (GOGLA 2021). Programs such as the International Finance Corporation's (IFC's) TechEmerge (focusing on India and Nigeria) are helping speed up innovation by financing pilots for game-changing technologies that may have applications in rural areas, including for cooling services (see Box 3.1).

BOX 3.1

IFC'S TECHEMERGE PROGRAM SUPPORTS GAME-CHANGING INNOVATION IN RURAL COOLING

TechEmerge is an award-winning program of the International Finance Corporation, which matches innovators worldwide with leading companies and organizations in emerging markets to pilot game-changing technologies, services, and business models. Sustainable cooling innovation is among the three focus areas of this program. Cooling is a focus not only because it is essential for economic development, productivity, human health, and food security, but also because it has significant climate impacts. Amid rising cooling demand, TechEmerge connects innovators and leading companies to pilot and accelerate the adoption of innovative, affordable, energy-efficient solutions. Some of its pilot cooling activities are likely to be applicable in rural areas, including technologies powered by off-grid electricity.

Since 2019, more than 135 ADOPTERS participated in matchmaking with over 60 INNOVATORS. Of these, 30+ INNOVATORS were matched with 45+ leading companies in emerging markets to implement more than 65 pilot projects. TechEmerge has so far supported these pilots with more than US$8.5 million in funding and technical support to field test and validate technologies.

Below are examples of TechEmerge's sustainable cooling pilots that could be applicable in off-grid rural areas:

- **Purix** has developed a solar-thermal-based absorption cooling technology, which, when combined with a small photovoltaic system, can provide 100 percent off-grid cooling at farm gate. It partnered with **Alyx**—a Nigerian company dedicated to developing cold chain solutions for farmers across Nigeria—to test the solutions' performance in two 5-ton storage facilities built using adobe blocks.
- India's **Ecozen**, a manufacturer of energy-efficient cold storage solutions, is joining with **Agvest Limited** and the engineering company Lange & Grant to field test a solar-powered cold room with water-based thermal storage backup for fruits, vegetables, and other agricultural commodities. The aim is to establish how the solution could be scaled up more widely in Nigeria and Africa.
- French innovator **Koolboks** has developed a technology that harnesses solar energy and stores it in the form of ice batteries, which are strategically arranged in freezers to maximize temperature retention. In this pilot, **Koolboks** is partnering with Nigeria's Fan Milk to pilot this Internet of Things–enabled technology to store milk, ice cream, yogurt, and other goods in retail stores.

(*continues*)

BOX 3.1 (*Continued*)

- Indian innovator **New Leaf Dynamic Technologies** partnered with the country's largest online grocery, **BigBasket**, to field test a GreenCHILL refrigeration system, which uses a natural refrigerant with zero greenhouse gas emissions. Pelletized cashew nut shells and waste husks from a BigBasket coconut processing factory provided biomass fuel for the GreenCHILL unit (see photo below).

Left: Prateek R monitors pilot equipment at a BigBasket distribution center in Hoskote, near Bengaluru, India. © IFC/Jdot Productions 2021. *Right:* Purix solar-thermal based absorption cooling technology, combined with a small photovoltaic system, installed in farm-gate storage buildings built with adobe bricks in Kanu, Nigeria. The system works 100% off-grid ©. IFC TechEmerge 2023.

Source: https://www.techemerge.org/

Resources must be channeled to support research and development and help potential technologies become financially viable. The Efficiency for Access Research and Development Fund has contributed US$2.11 million to support cooling innovations by 16 companies across all areas of domestic and light commercial/agricultural productive use applications. As noted in Box 3.1 above, IFC's TechEmerge Cooling program has so far provided more than US$8.5 million. Challenge prizes have also been used to stimulate innovation (see Box 3.2). Among the agricultural productive use applications, cold storage for horticulture is the most developed (almost universally solar powered). This is followed by the increasing adoption of solar refrigerators supplied under pay-as-you-use models for small-scale fisheries in West Africa and beyond. Cooling solutions also include some sustainable cooling facilities/appliances used in emerging markets such as Kenya and Nigeria, as well as the most currently advanced Indian market. These include solar-powered walk in cold rooms, zero-energy cool chambers, small-scale (milk) coolers, solar fridges and freezers (all using either conventional batteries or thermal storage ice battery/PCM [phase-change material] technology), and ammonia-based chillers and ice makers.

BOX 3.2

THE ROLE OF CHALLENGE PRIZES FOR INNOVATION IN COOLING TECHNOLOGY

The Challenge prizes led by the Collaborative Labeling and Appliance Standards Program (CLASP) have demonstrated the potential impact of sustainable cooling in off-grid settings. The prizes include the Global LEAP awards, which identify markets for refrigerators and fans and accelerate their development. Together with Efficiency for Access, the most recent Global LEAP award for off-grid cold chain technology (the Off-Grid Cold Chain Challenge) included the evaluation of the technological performance of 15 models of walk-in cold rooms and associated business models across Kenya, Nigeria, and India.

Other prizes in the sector include the Rocky Mountain Institute's Global Cooling Prize, which aimed to demonstrate the viability of a residential air-conditioning unit with a climate impact one-fifth that of current baseline units and an installation cost not exceeding twice theirs. Similar awards, including the Engineers Without Borders Chill Challenge, the Ashden Cool Cities Award, and the Million Cool Roofs Challenge, have proven to be catalytic forms of finance to incentivize innovation. Challenges help demonstrate the best available technology and acquire market intelligence through piloting programs, providing policymakers and development financiers with key insights on how to bring these technologies to scale.

The **off-grid fan** market is comparatively more established than the market for refrigeration and freezing appliances, as discussed below under space cooling. While off-grid fans are more expensive than regular fans for on-grid use, they are the most affordable of the off-grid cooling technologies and are increasingly available from off-grid solar system dealers.

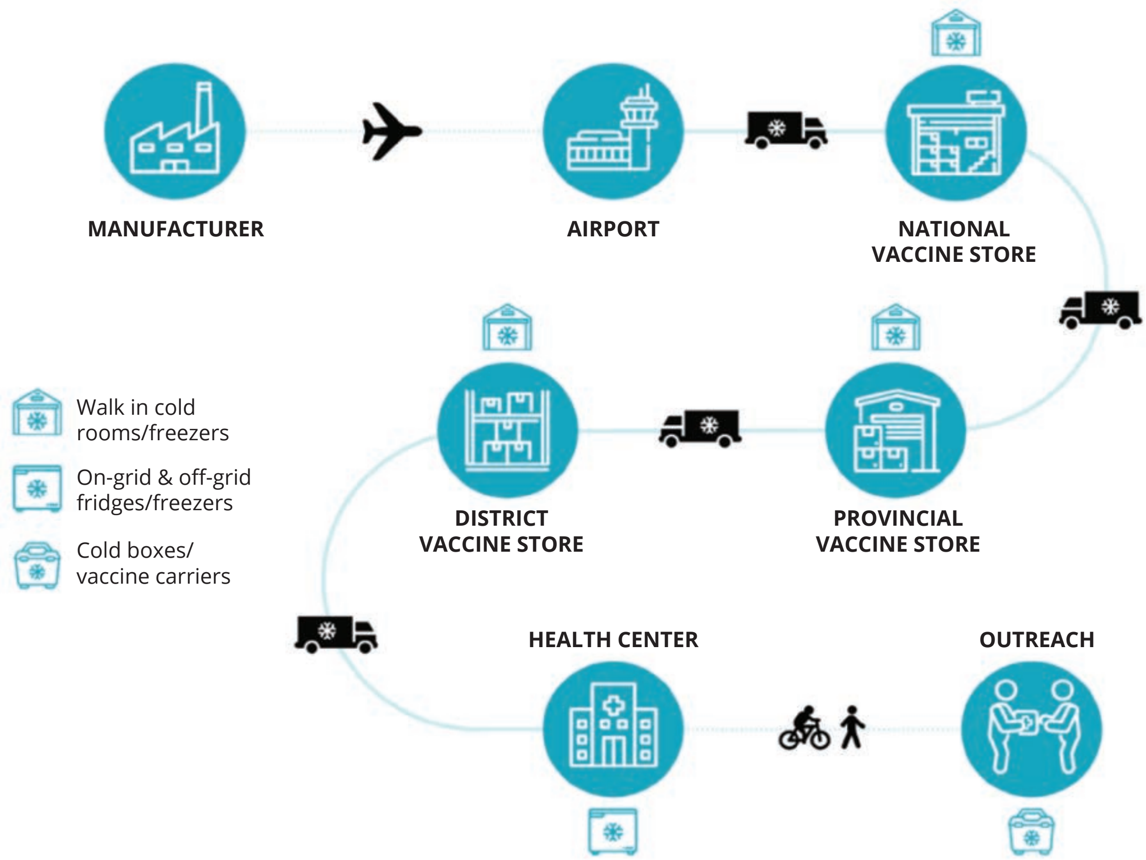
Off-grid refrigeration applications are at different levels of technology and market maturity:

- **Domestic and light commercial applications (refrigeration and freezers)** are already being sold in many markets, although their high unit cost presents a critical adoption barrier (Efficiency for Access 2023c). Domestic and commercial appliances have significant commonalities; units are typically below 250 liters in size, although appliances of up to 400 liters are available. Under VeraSol, the Global LEAP Off-Grid Refrigerator Test Method is now in the process of being formalized as a quality standard by the leading global body, the International Electrotechnical Commission, and field testing standards have been developed to demonstrate how a product may operate under "real-life" conditions (Efficiency for Access 2022b).

- **Small-scale light commercial agricultural applications** hold strong promise, although the technology is still relatively new, and remains unproven in many markets. These technologies include walk in cold rooms (including a small share of freezing rooms), milk chillers, ice makers, and electric chiller vehicles that are sized to serve producer cooperatives and to be used as part of aggregation and distribution chains rather than for use by individual farmers (Powering Agriculture 2020). Although this segment has a clear emerging leader, solar-powered walk in cold rooms, the technology is itself still relatively new to African and Asian markets (Efficiency for Access 2023a). Although walk in cold rooms have high capital and operating costs due to energy requirements, innovation related to solar direct drive technology can eliminate the use of expensive batteries to store energy and help save on operating expenditure (Efficiency for Access 2021b). Increasingly, cold storage rooms use purely solar direct drive technology, integrating some form of PCMs[2] or "ice batteries" to enhance energy efficiency and retain sufficiently low temperatures for use off-grid when the sun is not shining. Combining such technological improvements with cooling as a service (CaaS) business models can help unlock cold chains that may enable developing countries to increase food supply 15 percent—about 250 million tons (NextBillion 2020).
- **Clinical/health care applications** are already viable for off-grid refrigeration and have attracted substantial interest and investments due to the COVID-19 pandemic. This is a mature technology segment that is subject to rigorous performance standards given the critical need to store vaccines, other medicines, and blood products within permissible temperature ranges (developed by the United Nations Children's Fund [UNICEF] and the World Health Organization [WHO]). Recent innovations in fridge insulation, efficient compressors, and better controllers are driving down costs and improving efficiency and durability. One example is the use of PCMs, which are increasingly being incorporated into domestic and light commercial off-grid and weak-grid cooling technologies (Energy for Access 2021b). This allows less compressor runtime while maintaining the cooling temperature and minimizes or completely eliminates the use of more expensive electrical battery storage (Efficiency for Access 2021c). Another trend is the use of superefficient variable-speed compressors that use permanent magnet motors, which are more efficient and easier to install and maintain since they are often smaller than standard motors.

Diverse technical solutions and transportation/delivery models exist in different cold chain segments, whose local conditions also vary. For example, delivery of vaccines, other medications, and blood products for health care requires cooling-equipped transport, as well as refrigerated storage facilities along the entire chain from the manufacturer to the local point of use (see Figure 3.2 for an example of the vaccine cold chain). Cooling facilities are required at the manufacturing facility, in vehicles used for land and airline transport, in storage facilities at national and provincial level (walk-in cold rooms), in local clinics and other facilities (on and off-grid fridges and freezers) and, finally, to get products to the site of use (cold boxes).

FIGURE 3.2
Vaccine Cold Chain Structure

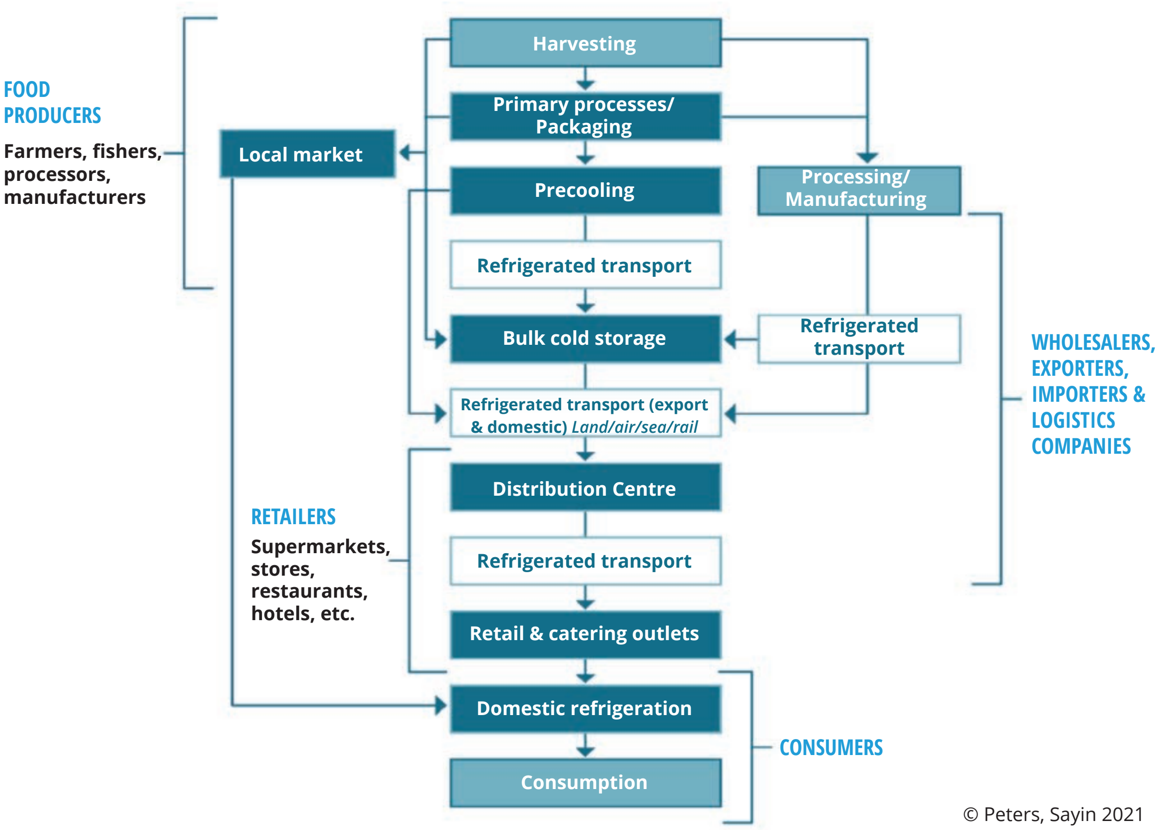


Source: SEforALL 2020b.

For the agricultural value chain, the cooling process begins with having access to micro, small, and medium cold storage facilities at the "first mile," where food is produced or caught. Subsequently, an unbroken cold chain becomes essential to ensure food remains chilled as it is transported from the point of production and distributed to retailers, ideally extending cold storage to homes and wherever food is consumed. This raises fundamental challenges to "energy access" since most areas in emerging markets where food is grown, fish are harvested, or cows are milked are rural and either lack electricity access or have highly limited and unreliable access (Efficiency for Access 2023b). Solar-powered cold storage appliances (e.g., refrigerators and freezers of approximately 100–400 liters capacity) and facilities (e.g., walk in cold rooms or more advanced chilled packing and processing facilities of at least 10–30 cubic meters [m^3] capacity) are the most prevalent emerging solutions (see Figure 3.3).

FIGURE 3.3

Agriculture Cold Chain and Stakeholders



Source: Cool Coalition 2021.

Off-Grid Space Cooling Solutions

Off-grid space cooling solutions (other than fans) have seen limited implementation, even though their importance is growing in light of the increasingly frequent heat waves and warming climate conditions affecting different regions in recent years. Below is a summary of some of the available off-grid cooling solutions that are suited to meet the rural demand.

PASSIVE SPACE COOLING SOLUTIONS

Based on heat tolerance, passive cooling solutions can deliver thermal comfort without consuming energy when they are applied properly. Passive solutions should be the first and the most immediate approach to off-grid rural cooling, since their use can reduce the energy requirement for active cooling even when they cannot deliver adequate thermal comfort independently.

Cool roofs are typically cost competitive with traditional roofs in established markets. They have a simple economic payback period of 0–6 years based on energy savings alone, even before considering social benefits (ESMAP 2020). In rural areas in developing economies, up-front costs can be expected to vary, although in some cases, they represent a potential key area of public investment due to the nascency or nonexistence of supply chains of active cooling equipment.

Depending upon the setting and outdoor air temperature, the simple act of painting a roof white can lower indoor ambient air temperature by an average of 2–5°C, even though potential reductions can be as high as 10°C in certain cases (SEforALL 2021a). Cool roofs have primarily been tested for efficacy in reducing temperature in urban settings. This is because they also reduce the urban heat island effect. However, cool roofs also have clear applications and similar benefits in rural settings since the science is the same. One study in a rural area near Hyderabad, India, found that the implementation of a cool roof on a school reduced the average classroom temperature by 2.1°C and peak temperature by 5°C relative to uncoated classrooms (Garg et al. 2015).

Vegetation, shading, and natural ventilation for rural homes and buildings are other effective passive solutions that can enhance thermal comfort and productivity for rural communities. Where water resources are sufficient to make "green" roofs viable, they share many benefits with cool roofs. Trees can reduce heat discomfort for outdoor workers by providing shade. They can also enhance comfort indoors when adjacent to buildings. Before resorting to electricity-powered solutions, passive cooling should be maximized through enhanced building design and orientation to take advantage of ventilation and wind-induced cooling. The IFC's Excellence in Design for Greater Efficiencies (EDGE)[3] design certification supports sustainable building design, and its rural application could be explored more extensively to support off-grid cooling.

ACTIVE SPACE COOLING SOLUTIONS—FANS

Fans for off-grid use (e.g., with DC motors) are the primary electrical cooling appliances for thermal comfort in some homes in rural off-grid areas. Although more expensive than regular fans for on-grid use, they can be a cost-effective—albeit limited—solution for thermal comfort during heat waves (when compared with air-conditioning units, which are costlier and consume much more energy) and help boost workplace productivity and create an environment of comfort for sleep compared with other active solutions. In a survey of off-grid customers in Bangladesh, 81 percent reported that fans had improved their quality of life, besides extending daily productive time by 2 hours and 20 minutes on average (Efficiency for Access 2021d). Fans also effectively provide space cooling in agricultural settings. For example, they are used for livestock cooling. They are also used in rural health clinics and in schools with limited or marginal electricity access that cannot provide air-conditioning.

The off-grid fan market is comparatively more established than the market for refrigeration and freezing appliances. An estimated 1.08 million fans were sold in 2022 (GOGLA n.d.). This off-grid market covers 40 percent of rural areas in India, Nigeria, and Bangladesh (Efficiency for Access 2019a). This relatively higher coverage is due to the greater affordability of fans and their efficiency. Comparing market samples between 2016 and 2019 shows a 57 percent efficiency improvement, partly due to the growing incorporation of brushless or permanent magnet DC motors. By one estimate (Efficiency for Access 2021e), prices of fans fell by 47 percent between 2016 and 2018.

Off-Grid Solutions for Refrigeration

Refrigerators and freezers are essential for homes, agriculture, and health services. Table 3.1 provides an overview of the different off-grid refrigerator types. Refrigerators and freezers can be operated continuously using PV panels, electrochemical batteries, or PCM/thermal storage/ice batteries, and insulation. However, solar refrigerators have limited penetration in weak- or off-grid areas, largely due to their high costs and limited availability, and the limited development of business models for equipment and power provision for productive use. Household ownership of solar refrigerators in rural Africa accounts for a meager 4 percent, whereas it is a modest 16 percent in rural India (Efficiency for Access 2019a). For Sub-Saharan Africa, survey data on the solar appliance market suggest limited diversity among purchasers, who are typically men, living with their families in a rural or peri-urban area, with inclusion in the financial systems and access to a grid connection. Although solar refrigerators are perceived as impactful for women, only 39 percent of reported owners are female (Efficiency for Access 2022a).

The benefits of access to refrigeration for rural households have been documented. One project in Kenya estimated average savings of US$4.82 per week through improved ability to store perishable food and reduced shopping time (Efficiency for Access 2021f). Access to refrigeration also supports productive use in rural areas. It enables small businesses to store food and beverages for sale, minimizes crop waste for higher yield, and extends the storage period in agriculture and fisheries.

TABLE 3.1

Off-Grid Refrigerator Types

REFRIGERATOR TYPE	DEFINITION	APPROPRIATE POWER SOURCE
Absorption refrigerators. Operate on a heat cycle, which requires a fuel- or electricity-based heat source		
Gas or propane refrigerators	They use gas or propane as their primary energy source and have no moving parts. Their energy consumption is substantial, and they pose potential fire and health risks due to particulates.	Gas or propane fuel
Compression refrigerators. Operate on a compression cycle, which requires electricity		
Direct current household refrigerators and refrigerator-freezers	They are designed to be used with a solar energy system and typically feature more efficient design considerations, for example, highly efficient compressors and motors, or thicker insulation.[d]	Solar systems, including photovoltaic panels and batteries, or generators
Solar direct drive (SDD) refrigerators	They connect directly to a photovoltaic panel and typically include an integrated thermal and/or electrical battery to allow autonomous operation at night or on cloudy days, when there is no solar power. The SDD technology uses solar energy to freeze water packs or other phase-change materials. The ice packs keep the refrigerator cool.	Photovoltaic panel
Conventional alternating current refrigerators	These are intended for use with a grid power supply but may be used with a solar system through an inverter. On average, they are less efficient than direct current refrigerators but are currently the most readily available option for most off-grid consumers.	Grid electricity, a generator, or a solar system with an inverter
Evaporative refrigerators. Utilize water and an evaporative effect to cool without a power source		
Evaporative refrigerators	They have a simple design, which utilizes water and a porous membrane to cool through evaporation. Evaporative refrigerators are effective only in low-humidity areas and can only cool by 10–15°C relative to ambient temperature. Handmade clay pot coolers are one of the most common designs, although some companies have developed designs for the mass market. The mass market designs use an internal reservoir filled with water and lightweight membranes as insulation.	No power source needed

Source: Efficiency for Access 2021a, b, c, d, e, f.

Optimizing off-grid refrigerators for price and efficiency is a significant challenge. However, donor funding has enabled market leading companies to improve efficiency through R&D. The use of a refrigerator for commercial purposes consumes more electricity than its domestic use. This is because commercial refrigerators have a higher produce throughput, must be able to cool rapidly, and must be able to maintain lower temperatures, for example. Therefore, it is not uncommon for a 200-liter commercial solar fridge to require approximately 300 watts-peak of solar power. Other variables, such as the ambient environmental temperature and the amount of solar radiation, are also important determinants (Efficiency for Access, 2023c).

Affordability remains a key market barrier to the mass adoption of off-grid refrigerators, which can cost 2.5 times as much as the annual disposable income of the poorest 50 percent of off-grid households (Efficiency for Access 2021e). In rural parts of developing countries, maintenance requirements related to product failure and warranties are another key barrier (Efficiency for Access and 60 Decibels 2023). This barrier can be addressed by increasing the number of trained local technicians. Further, manufacturers and distributors face hurdles in reaching out to rural consumers, making it difficult to deliver goods and provide after-purchase services (Efficiency for Access 2019a).

Off-Grid Solutions for Cold Chains in Rural Settings

Walk in cold rooms are high-capacity cold storage facilities for products such as postharvest agricultural produce and vaccines. An important example of their use for vaccine storage was an ESMAP program in Mongolia that upgraded its vaccine storage capability and supported a major COVID-19 vaccination program (see Box 3.3). Besides the safe upkeep of life-saving vaccines, they hold potential to boost agriculture-based income through reduced food wastage and increased shelf life of fresh produce. This is especially vital considering the impacts of the COVID-19 pandemic, historical and future droughts, and the need for greater climate resilience worldwide.

The smallest functional cold rooms are approximately 10 m^3 and can store about 3 tons of produce (depending on the cold room's volume and density). The largest standard units are used for temporary storage and are approximately 30 m^3 in aggregate. They have associated solar power systems, which range from several kilowatts to 10,000 kilowatts-peak and more (Efficiency for Access 2021b). However, much larger units can be utilized for longer-term storage or industrial purposes.

BOX 3.3

ESTABLISHING CLIMATE-FRIENDLY VACCINE COLD CHAINS IN MONGOLIA

When the COVID-19 pandemic began, the Energy Sector Management Assistance Program (ESMAP) swiftly reoriented its activities and shifted priorities to help mobilize technical and financial resources to support vaccine deployment. ESMAP, in partnership with the Government of Mongolia and other members of the World Bank's COVID-19 Vaccine Delivery Taskforce, upgraded Mongolia's cold chain storage and redesigned its central vaccine store. In August 2021, Mongolia opened a new central vaccine facility equipped with over 10,000 pieces of energy-efficient, modern equipment (World Bank 2022b). With other financing, 800 refrigerators and 34 types of ultra-cold chain equipment were purchased, and 10 cold rooms were installed in central warehouses and vaccination units country-wide. This infrastructure upgrade enabled every vaccination unit in the country to receive and properly store vaccines delivered from the central warehouse (WHO 2023b). As of March 2022, Mongolia had administered roughly 5.5 million doses of COVID-19 vaccines—enough to have vaccinated over two-thirds of the country's population with two doses and over a third with an additional booster dose, according to the World Health Organization in Mongolia (see Appendix A for details).

Vaccine storage facilities in Mongolia. *Source:* World Bank-ESMAP publication/UNICEF.

There are major obstacles to the large-scale deployment of walk in cold rooms: high capital costs, high operating and maintenance costs, and the need for new business models and effective supply chains (Efficiency for Access 2021b). Cost reduction requires innovation in several areas, including cooling techniques (vapor compression cycle versus vapor absorption cycle),[4] insulation material, energy consumption intensity, energy storage, and low-global-warming-potential refrigerants. Further, there is limited evidence about widespread economic demand in specific markets, the technology's commercial readiness for uptake, and the potential costs to deliver the necessary after-sales service and maintenance to ensure reliable operation (Efficiency for Access 2021b). While over 1,000 walk in cold rooms have been deployed in India, markets remain nascent and largely undeveloped elsewhere. Of the approximately 10 million African smallholder farmers cultivating cold-storage-dependent products, only 36 percent have electricity access and 62 percent cannot afford cooling technologies (Energy 4 Impact 2020).[5]

Mapping Cooling Technologies to the Energy Access Multi-Tier Framework (MTF)

Efforts have been made to characterize the off-grid cooling appliances market and its relationship to electricity access. Sustainable Energy for All (SEforALL) and the Collaborative Labeling and Appliance Standards Program (CLASP) assessed the current efficiency levels of cooling technologies and their suitability for off-grid settings in a report titled “Raising Ambitions for Off-Grid Cooling Appliances’ (SEforALL and CLASP 2021). This effort was intended to understand the technologies’ applicability at various levels of electricity access as defined by the Energy Access Multi-Tier Framework (MTF). The report found that energy efficiency improvements have made cooling services available at lower tiers of electricity access, and that a meaningful link between the MTF and off-grid cooling appliance standards can ensure investments are mutually reinforced and beneficial (Box 3.4).

BOX 3.4

THE ENERGY ACCESS MULTI-TIER FRAMEWORK

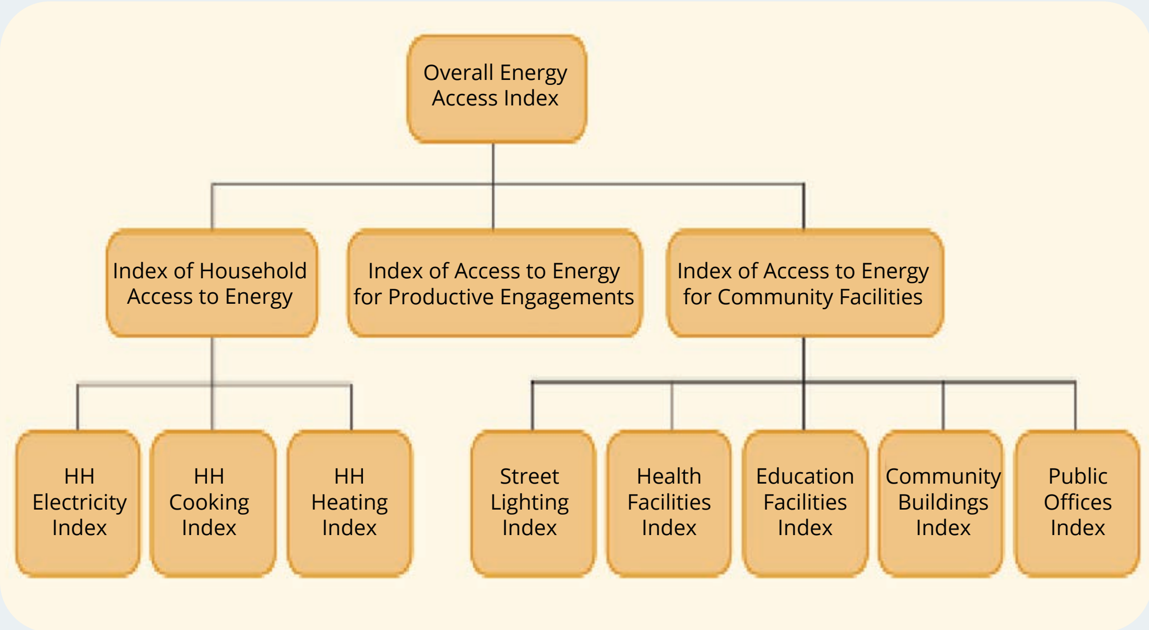
The Multi-Tier Framework (MTF) was a pioneering effort in reconceptualizing energy access from a service quantity and service quality perspective. It provided comprehensive definitions of energy access and corresponding measurable indices by considering three broad energy use categories: (1) households; (2) productive engagements; and (3) community facilities such as health facilities, educational institutes, and public buildings. Besides providing an overarching framework for each use category, the MTF was further extended to energy use subcategories (e.g., household space heating and street lighting). Energy access levels were divided into tiers based on the quantity and quality of energy services that the user could access. Notably, this approach eased gaps and facilitated other multifaceted analyses. This made more focused interventions for universal access possible, for example, in terms of program design and investments (more details on the MTF are provided here).

(*continues*)

BOX 3.4 (*Continued*)

FIGURE B2.3.1

Hierarchy of Energy Access Indices



Source: World Bank 2015.

Note: HH = household.

To better understand households' level of access to electricity resources and provide a more nuanced view on achieving Sustainable Development Goal 7, the World Bank's Energy Sector Management Assistance Program (ESMAP) identified key attributes within the MTF for defining and measuring household electricity access: peak capacity, affordability, availability (duration), reliability (absence of supply interruptions), quality (voltage issues do not affect appliance use), health and safety (possibility of accidents), and legality (the utility or authorized entity provides or pays for energy).

Source: World Bank 2015.

The MTF (Figure 3.4) begins at Tier 0 (no household electricity access) and goes up to Tier 5 (sufficient for continuously operating high-power-consumption appliances) progressively, measuring the electricity services needed to power certain combinations of services (Box 3.4). Across this range, access to cooling can begin with passive solutions at Tier 0, followed by Tier 1 electricity access, which is required to operate active personal cooling solutions.

FIGURE 3.4

Off-Grid Cooling Appliances Applied to the MTF Household Electricity Access Tiers

		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
TIER CRITERIA			Task lighting and phone charging	Task lighting, phone charging, television and fan	Tier 2 and any medium-power appliance	Tier 3 and any high-power appliance	Tier 4 and very high-power appliance
PEAK CAPACITY	Power capacity ratings (in W or daily wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
			Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 W
AVAILABILITY	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
	Hours per evening		Min 1 hr	Min 2 hr	Min 3 hr	Min 4 hrs	Min 4 hrs
FANS							
REFRIGERATORS							
REFRIGERATOR-FREEZERS							
AIR COOLERS							
ACS							

Note: AC = air conditioner; kWh = kilowatt-hour; MTF = Multi-Tier Framework; Wh = watt-hour.

For off-grid settings, where access to reliable electricity or basic electricity services from an electricity grid may be absent altogether in the foreseeable future, cooling needs will have to be met through greater access to the increasing number of reliable, efficient, and high-performance stand-alone or off-grid active cooling technologies that are becoming available as well as using passive cooling solutions. Needless to say, the first step toward cooling anywhere is to reduce the cooling load. In buildings, this means insulating, providing shading, or reflecting heat. In agriculture, it could mean providing shade for workers or livestock, or storage for produce. Additional measures such as natural ventilation to allow air movement can also enhance thermal comfort.

Affordability of Off-Grid Cooling Technologies for End Users

Efforts to increase cooling access for off-grid rural populations must first consider the affordability of cooling equipment/appliances or services for end users. Promotional efforts will need to target the likely end users for different applications. For space cooling, households, schools, clinics, and public buildings are the likely users, for example. For refrigeration, the end users could include households, small retail businesses and restaurants, and smallholder farmers and fishermen. For cold chains (refrigerators, cool storage, and cold rooms), the end users could include smallholder farmers, farmer groups, and their clients who may aggregate purchases of food products (e.g., produce, fish, dairy, meat); municipal authorities responsible for local markets; and health authorities, which need cold chains for vaccines and medicines.

Assessing the affordability of cooling equipment for end users requires (1) data on the end users' income and/or the expected benefits to them (revenue and other non-monetary) from access to the cooling appliance or service, and (2) technology- and site-specific data on the costs of the cooling equipment and the cost to purchase or upgrade the off-grid power system, if required, both of which depend on the local terms of purchase (cash or credit for equipment or periodic payment for service). Since this report discusses cooling needs in off-grid areas, obtaining technology- and site-specific data is difficult. In light of this, the discussion below can only be seen as indicative since generalizing based on specific examples is not prudent. Table 3.2 provides an indicative range for the costs in Sub-Saharan Africa of different cooling appliances that are discussed in the following sections; actual values in any location could differ.

TABLE 3.2

Market Pricing for Commercially Available Off-Grid Rural Cooling Technologies

SECTOR	APPLIANCE TYPE	SIZE SUB-CATEGORY	PRICE (US$)	INDICATIVE SUPPLIERS
Households/ agriculture/ enterprises	Refrigerator or freezer, or variable-temperature unit (including a solar power and storage system)	<200 liter (L) 200–400 L >400 L	600–2,700 1,200–3,500 1,240–3,800	Devidayal, Koolboks, Palfridge, Sola-Run, Steca, SunDanzer, SureChill
	Walk-in cold room (including a solar power and storage system)	<5 metric tons	10,000–30,000	Ecozen, Fresh Box, InspriaFarms, Self Chill
Space cooling	Table fans	100–380 millimeter (mm)	8–61	d.light, Metropolitan, Royal, Solar Run, SunKing, Super Star, Tamoor, VersaDrives
	Pedestal fans	320–650 mm	17–62	
	Ceiling fans	1,000–1,400 mm	14–65	

Sources: Lighting Global et al. 2022b; According to Efficiency for Access 2024.

Note:

1. Pricing for refrigerator and freezer/variable-temperature units includes appliances of the size range that have power demands depending on their temperature and other variables.
2. Pricing for the first two categories of refrigerator/freezer and walk in cold room includes a solar power and storage system (using electrical batteries or "ice batteries" using phase-change materials, or a combination of the two).
3. The average price of a table fan was US$43, pedestal fan was US$39, and ceiling fan was US$38.
4. Pricing is at retail value in Sub-Saharan Africa (including taxes, duties, shipping costs, and profit margins).

Income Levels in Off-Grid Rural Areas Indicate Cooling Affordability Challenge

Little is known about the characteristics of off-grid areas worldwide, including information on the income levels of their residents. However, it is likely that income levels in off-grid areas that often lack not only electricity but other infrastructure would be lower than in more accessible areas; this will make expanding access to cooling services there a significant challenge. Indications about income in off-grid areas are available from a few sources. As already noted, SEforALL estimates that 306 million rural residents living in poverty are at high risk due to lack of access to cooling. The risk factors for the people in this group include no electricity access and incomes below the poverty line of US$2.15 per day (SEforALL 2023). These are the most vulnerable people, who need the most support to benefit from cooling services.

GOGLA, the global association for the off-grid solar energy industry, estimates that 493 million people had access to electricity through solar energy kits in 2022, and that a majority of these, or at least 250 million people, lived in rural areas (Lighting Global/ESMAP et al. 2022b).[6] These people, who already have access to off-grid solar electricity, can also use cooling appliances, although they may need to increase their systems' capacity beyond supporting lighting and mobile phone charging. GOGLA indicates that a typical off-grid rural customer lives on less than US$3.20 per day, has some limited savings, and seasonal fluctuation in income with harvests, whereas a typical smallholder farmer earns US$5.50 per day, has limited savings, and may have an additional income source. This information indicates that GOGLA's typical rural customers, many of whom also require cooling, have incomes that are not much above the poverty line. These off-grid customers are less well off than the typical urban/peri-urban solar energy kit users, whose incomes are below US$10 per day.

While the distribution of incomes around these typical off-grid customers is unknown, it is likely that their ability to purchase off-grid cooling equipment and services would be limited by relatively low incomes and savings levels. As discussed below, this will vary by appliance type. While many people may be able to afford to purchase an off-grid fan with cash payment or installments, few will able to afford a refrigerator even if financing is offered. Even for a fan, the most vulnerable and those living at or below the poverty line may require a significant up-front subsidy.

Affordability of Off-Grid Space Cooling for Safety and Comfort

As noted above, off-grid fans are commercially available and are the main appliances for space cooling in off-grid rural homes, health clinics, schools, shops, and other buildings, as well as for cooling indoor farm areas. As noted earlier, the only source of data is from GOGLA affiliates, who sold about 1 million fans for off-grid use worldwide in 2022 (GOGLA n.d.), indicating a total worldwide market of 2–3 million fans (low-end assumptions double GOGLA affiliates' sales, whereas the high end assume affiliates' sales are about 30 percent of total, the same share as for unit sales of off-grid solar kits). While some of these fans for off-grid use are sold to residents of urban areas with weak or unreliable grid service, since they are much more expensive than fans for on-grid use, it is likely that the majority are sold to people in rural off-grid areas (Lighting Global/ESMAP et al. 2022b). Assuming that 1–1.5 million fans are sold worldwide per year to off-grid areas, this represents a small proportion of the total off-grid households and indicates a substantial cooling gap.

The benefits of fans are perceived as substantial by those who can afford them. In a survey of off-grid customers in Bangladesh, 81 percent reported that fans had improved their quality of life, besides extending daily productive time by 2 hours and 20 minutes on average (Efficiency for Access 2021d). Also, the case study in Box 4.2 illustrates that the World-Bank-funded Sindh Solar program in Pakistan found that including a fan with solar home systems (SHSs) helped create a demand for high-quality SHSs.

Up-front costs can hinder fans' purchase as these costs represent a significant proportion of household income. In India, a solar home system kit with a fan costs approximately US$80, more than 50 percent of an average consumer's monthly income (Efficiency for Access 2022a). Assuming that a fan costs about US$40 on average and that rural residents with off-grid solar kits earn on average US$3.20/day or US$96/month, it would take them about 4 months to purchase a fan with cash by saving 10 percent of their income.[7] While possible, this is a stretch since many consumers would also need to buy a solar kit or upgrade its capacity to achieve this level of service.[8]

Making off-grid fans affordable for households and farmers will likely require some form of expanded public support akin to that provided for solar home kits, which typically require at least pay-as-you-go (PAYG) credit options to reach the better off in off-grid areas. However, reaching the most vulnerable would require end user subsidies, and sellers would need to be offered concessional financing to support the early development of commercial markets.

A set of interrelated factors create promising conditions for promoting access to off-grid fans: they use little energy, they can be bundled alongside sales of solar energy kits, they are relatively low cost (e.g., compared with refrigeration or air-conditioning), they are the only affordable means of reducing heat in off-grid settings, they help create a demand for off-grid solar energy kits, and they are already being sold through existing SHS product offerings and distribution channels.

Affordability of Off-Grid Cooling for Agriculture, Food Security, and Nutrition

One important way to reduce food wastage and improve the economic situation of the residents of rural off-grid areas is to expand access to cold chain facilities that extend the life of produce through efficient storage and transport. This section will first discuss what are generally referred to as solar refrigerators and freezers for domestic and light micro, small, and medium enterprise/commercial use. Then it will look at larger commercial cold storage facilities for agriculture.

Domestic and light commercial refrigeration and freezers are being sold for off-grid use by a limited number of suppliers. The high cost of appliances for this nascent market remains a critical adoption barrier. Supply of these off-grid cooling appliances is dominated by large global corporations, making these appliances significantly more expensive than typical on-grid appliances, which have economies of scale. Off-grid refrigerators and freezers are considerably more expensive and require that the end user also has or purchases an off-grid power system, typically solar. Domestic and light commercial appliances for use in small shops and by agricultural producers are typically 100–250 liters in size. Sizes around 200 liters are the most common, although units of up to 400 liters are also available. GOGLA affiliates sold an estimated 7,400 refrigeration units in 2022 (GOGLA n.d.), up from 6,300 units in 2021 (Lighting Global/ESMAP et al. 2022b). Global sales may be 2 or 3 times affiliates' sales, based on the same logic used to estimate global fan sales. The cost of such units has been estimated at US$600–US$2,700 for units up to 200 liters and US$1,200–US$3,500 for units of 200–400 liters (see Table 3.2 above for price ranges for approximate main product categories.)

Using GOGLA estimates, that the average rural off-grid customer earns about US$3.20 per day and the average smallholder earns US$5.50 per day, it is clear that unless a customer has savings or another income, domestic refrigerators and freezers are out of their reach, even if units can be purchased over several years on credit.[9] These appliances are likely purchased by small shops and businesses where costs are offset by the revenue generated by providing services such as cold drink sales, and by other produce or reduced produce spoilage. However, the worldwide small sales of such appliances indicate the technology's early-market state and its limited affordability given high costs (Efficiency for Access 2023c).

An example of interventions needed to increase affordability could be the case of the leading business model for solar-powered refrigerator/freezers, where a trader or fisherman purchases the appliance and the solar power system on "PAYG" terms from an off-grid solar/appliance distributor, which bears the assets' cost until it is paid in full. Making the appliance affordable would likely require an up-front end-user subsidy along with making concessional financing available to the dealer to enable the development of a new business line.

Larger commercial agricultural cooling facilities hold strong promise for delivering multiple benefits (these range from reducing food waste and spoilage, increasing revenues and incomes as well as reducing high global warming potential emissions). These emerging technologies include stand-alone refrigerators and freezers, walk in cold rooms (including a small share of freezers), milk chillers, ice makers, and electric chiller vehicles that are sized to serve producer cooperatives or "cooling as a service" providers and to be used as part of aggregation and distribution chains (USAID 2020).

Combining technological improvements with effective business models (e.g., CaaS, where customers pay for cooling based on usage rather than purchasing cooling equipment) can help unlock cold chains (Efficiency for Access 2021b). Although the technologies, business models, and financing mechanisms are still relatively new and their long-term commercial viability remains unproven in many markets, progress has been made with innovative cold chain business models aimed at increasing affordability. Entrepreneurs and technology providers are starting to explore rental-based and on-demand business models to preserve fresh produce at source and enhance quality throughout the supply chain (Efficiency for Access 2023a).

Larger off-grid-appropriate (DC-powered) refrigerators and freezers have a power demand that is typically met using distributed renewables such as stand-alone solar energy. Their retail price ranges from US$1,240 to US$3,800 (see Table 3.1) depending on factors such as appliance size, distance of user from manufacturing location, and import and sales taxes. The productive use of these appliances for the temporary storage and sales of fish, milk products, and other retail products has been shown to cover their cost within months to up to 2 years, as long as the underlying business is commercially viable.

Larger "facilities" such as walk-in cold storage rooms have higher power requirements, typically between 3,000 watt-peak (Wp) and 10,000 Wp. Such a walk in cold room would cost about US$10,000–30,000 in Sub-Saharan Africa (see Table 3.2) (including components' import, transport, taxes, and installation of the cold room and its power system) (Efficiency for Access 2021a).[10]

Sales and servicing for stand-alone appliances, larger walk-in cold storage rooms, or vehicles use three broad types of business models (see Section 4.1 for details): (1) direct cash purchase by an end user from a retailer; (2) asset finance/leasing, where an end user (typically a farmer producer organization, a small business, or a CaaS operator) enters into an agreement where they own a cold storage asset after making full payment for it over time; and (3) the CaaS model, where an owner/operator owns a cooling asset such as a walk-in cold storage room while the end user(s) pay(s) for the services delivered by the asset (Efficiency for Access 2023c).

GOGLA estimates the market for cold storage among farmers by assuming that a number of farmers would group together to purchase cooling units or cooling services.[11] GOGLA estimates that about 12 percent of smallholder farmers in Sub-Saharan Africa could afford to buy cold storage services (0.89 of 7.4 million) at an average capital cost for facilities of US$332 per farmer. For India, GOGLA estimates that about 30 percent of smallholder farmers could afford to buy cold storage services with an average capital cost of US$196 per farmer (Lighting Global/ESMAP et al. 2022b).[12] Energy 4 Impact 2020 estimates that of the approximately 10 million African smallholder farmers cultivating cold-storage-dependent products, only 36 percent have electricity access and 62 percent cannot afford cooling technologies (Energy 4 Impact 2020).

While opportunities to reduce food wastage are great and developments are moving fast, major obstacles to the large-scale deployment of cooling/cold storage facilities in agriculture must still be overcome to make such facilities available and affordable for the majority of small farmers. As discussed in Section 3.1, the obstacles include high capital and operating costs, and high maintenance costs; the need for new business models that permit affordable payment for a reliable service; and the lack of effective supply chains to ensure reliable operation and maintenance. While some markets (where cooling facilities are produced domestically and used largely by farmer-led co-operatives, and government subsidizes facility sales) have shown significant progress—for example, the deployment of over 1,000 walk-in cold rooms in India—markets remain nascent and largely unorganized elsewhere (e.g., in Sub-Saharan Africa, across which only approximately 100 such cooling facilities are known, reflecting the lack of promotion and support).

Affordability of Off-Grid Cooling for Health Care

Cooling access is vital for storing vaccines, other medications, and blood products; for operating many types of critical medical equipment; and for thermal comfort in hospitals and health centers in rural areas.

Solar direct drive (SDD) refrigerators have been widely used to deploy vaccines and serve other health needs in unelectrified or under-electrified rural areas, to replace the less reliable and less environmentally friendly liquefied petroleum gas (LPG)–powered or kerosene-powered refrigerators (known as absorption-based refrigerators) since 2014 (WHO 2017). The WHO estimated annualized capital and operating costs for different types of vaccine refrigerators (40–60 liters) that meet its performance requirements as follows: SDD vaccine refrigerators, US$682; solar-battery-powered vaccine refrigerators, US$741; grid-powered vaccine refrigerators, US$355; LPG-powered vaccine refrigerators, US$788; and kerosene-powered vaccine refrigerators, US$800 (WHO 2017). Their analysis shows that while annualized costs for SDD refrigerators are about double the cost for conventional grid-powered refrigerators, they are about 15 percent lower than the annualized costs for fossil-fuel-powered refrigerators, while SDD refrigerators do not emit greenhouse gases. SDD refrigerators can also outperform conventional refrigerators in terms of maintaining the required temperatures in locations with weak and unreliable grids. In many developing countries, GAVI (the Global Alliance for Vaccination and Immunization), has provided governments with grants to procure SDDs. The procurement is usually conducted by UNICEF, which is able to source systems at a competitive cost through bulk procurement, including a maintenance contract for a fixed duration.

While a solar-powered refrigerator provides cooling for critical vaccines, powering an entire off-grid clinic requires a larger, more expensive and extensive solar system, which can provide additional services such as space cooling by powering fans along with other critical equipment. Parallel initiatives have therefore been developed to power vaccine cold chains while also pushing for the sustainable electrification of off-grid health care facilities. If the off-grid energy source is reliable, it should ideally also electrify the cold chains, thus precluding the need for SDDs, in turn saving on cost. Most such public institution electrification projects have been funded by grants and donor-supported initiatives focusing primarily on the procurement of solar assets. Increased focus is needed on ensuring and financing adequate operation and maintenance services over the equipment's life (SEforALL 2019b). The energy service company model is one potential way to mitigate sustainability risks. For example, a government selects a service provider (e.g., for installing and operating PV systems and the related equipment in a clinic), typically for 10–15 years, and pays for the services over the contract life (World Bank 2020b). Another method to support sustainability, as mentioned above, is bulk procurement that includes a long-term maintenance contract.

Despite the many demands on public funds, a number of governments and development organizations are working to address the challenge of providing electricity access and vaccine storage to health facilities using off-grid solutions. This is being undertaken through collaboration by stakeholders such as the World Bank/ESMAP, SEforALL, UNICEF, and GAVI.

For example, at least 30 countries, including Sao Tome and Principe, Nigeria, Togo, Somalia, Indonesia, and Kyrgyzstan, have procured, or are procuring, cold chain equipment such as SDD refrigerators using funds from such agencies as part of their COVID-19 response (reported in Lighting Global/ESMAP et al. 2022b).

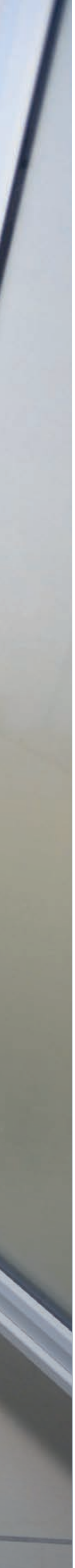
Endnotes

1. The Efficiency for Access Initiative provides significant resources for staying abreast of the latest solutions (e.g., Efficiency for Access 2021e).
2. PCMs collect thermal energy during the cooling cycle (powered in this context by solar electricity). This thermal energy is released during the melting cycle (https://en.wikipedia.org/wiki/Phase-change_material). For further context on PCMs, please refer to Efficiency for Access (2021c).
3. Learn more about the International Finance Corporation's EDGE building design certification at https://edge.gbci.org/.
4. "Vapor compression cycle (VCC) and vapor absorption cycle (VAC) are used in walk-in cold rooms to generate refrigeration" (Shakti Sustainable Energy Foundation and University of Birmingham 2019).
5. The Thirty-Fourth Meeting of the Parties to the Montreal Protocol on Substances that Deplete the Ozone Layer recognized this, with a request to intensify international coordination efforts to facilitate access to affordable energy-efficient technologies, and recommended actions to register acceptable energy efficiency thresholds.
6. Solar energy kits are at times purchased by residents of peri-urban and urban areas with weak and unreliable grid service. However, the majority of off-grid customers of solar kits are rural low-income households and microenterprises (Lighting Global/ESMAP et al. 2022b).
7. See Table 3.2. GOGLA reported the cost of a fan alone for off-grid use as follows: a table fan, US$8–US$61, average US$33; a pedestal fan, US$17–US$62, average US$39; and a ceiling fan, US$14–US$65, average US$38.
8. In comparison, GOGLA estimates that about 95 percent of the bottom income tiers worldwide could pay cash for a solar lantern in 2022 (average cost US$9), while 58 percent could afford to pay cash for a 1.5–3 Wp solar light and charger (average cost US$27). Both devices offer Tier 0 level service only. It is estimated that 62 percent could purchase a Tier 1 3–11 Wp multilight system (average cost US$91) with PAYG financing.
9. Calculations of energy affordability often assume that energy costs are affordable if they are below 5–10 percent of monthly income. Considering people must pay for energy costs before cooling costs, we assume that cooling costs would be affordable if the cash purchase price of an appliance could be saved in 3 months at a rate of 5 percent per month, or if the monthly payments for an appliance purchased on credit or via pay-as-you-go were below 5 percent per month.
10. The most comprehensive overview of the range of high-performance, high-quality solar-powered walk in cold rooms can be found in the Global LEAP Awards Buyers

Guide for Off-Grid Cold Chain Solutions, which showcases the technical specifications and performance of ten facilities in India, Kenya, or Nigeria (Efficiency for Access 2022c).

11. In Muzaffarpur, Bihar, farmers use a "pay-per-use cooling service" for perishable horticulture produce. This solar-powered service—launched by Oorja Development Solutions and Ecozen Solutions (Ecofrost)—allows farmers to store their produce on a per-crate-per-day basis. The 6 metric ton capacity Ecofrost cold storage is powered by a 5 kilowatts-peak solar PV system with PCM-based thermal energy backup (PV Magazine 2021).
12. Capital costs per farmer are estimated by dividing the total estimate of the value of the accessible market for cold storage for agriculture by the number of farmers in that market.

FOUR
OVERVIEW OF BUSINESS MODELS AND FINANCE FOR SUSTAINABLE COOLING IN RURAL OFF-GRID AREAS



This chapter provides an initial overview of emerging approaches to business models and financing mechanisms that enable bringing sustainable cooling appliances and facilities to off-grid rural areas. Section 4.1 focuses on business models and discusses how different options are used in meeting the cooling demand for space cooling, agriculture and food, and health care. Section 4.2 discusses the financing mechanisms that could be used to make sustainable cooling more affordable for customers in rural off-grid areas. The examples discussed need to be considered in light of the specific and local circumstances in off-grid areas such as geography, climate, socioeconomic conditions, availability of finance, market maturity, transport infrastructure, and availability of repair and maintenance services, while the references provide links to further information.

There is a strong potential overlap between the business models and financing mechanisms used for access to energy and those used for access to cooling for off-grid customers. The business models and financing mechanisms discussed in this chapter have been leveraged within the off-grid solar sector for more than a decade. Many of these instruments can be applied in the off-grid cooling sector, due to the similarities between the two markets. There is an overlap, on the demand side, of the consumers who are demanding both energy and cooling services and, on the supply side, of the product distributors or distributed energy service companies that are selling solar kits and high-performance cooling appliances or facilities for off-grid solar-powered space cooling and agricultural cold storage. Many lessons for today's challenge of making sustainable cooling accessible, can be learned from the global program to promote off-grid solar technology in rural areas, the Lighting Global/Lighting Africa Program, which has been conducted for the past 15 years with the support of the World Bank Group, the Energy Sector Management Assistance Program (ESMAP), and other partners (see Box 4.1).

Given that the international attention being focused on the cooling agenda in the developing world is relatively recent, further analytical work is needed to determine the applicability of business models and policies at commercial scale, to provide thorough insights into the circumstances under which each model is the most applicable and to develop effective policies and programs.

BOX 4.1

THE LIGHTING AFRICA/LIGHTING GLOBAL ROAD MAP TO OFF-GRID ENERGY ACCESS

The World Bank and the International Finance Corporation have supported access to off-grid solar lighting and electricity through their Lighting Africa and Lighting Global programs for nearly 15 years. They have leveraged project experience in individual countries to advance these initiatives. Today, the applications powered under this program encompass multilight systems, solar home systems, and appliances, including those for cooling. By 2021, an estimated 493 million people were using off-grid solar energy systems of various sizes, while the off-grid sector had attracted more than US$2.3 billion in investments and has played a key role in achieving universal access to reliable, sustainable, and affordable energy by 2030 (or Sustainable Development Goal 7.1)

The Lighting Global program (expanded from Lighting Africa) led the way in supporting the development of today's vibrant global market. Lighting Global's approach includes the following areas of interventions:

- **Market intelligence and knowledge sharing.** To understand consumers' needs and preferences, and their ability to pay; market bottlenecks; and distribution channels, Lighting Global conducts extensive market research and shares the findings to inform business decisions and policy interventions. These documents, together with convening knowledge exchange opportunities—including webinars, training programs, and the premier Off-Grid Solar Forum and Expo held every two years—encourage sector growth, through collaboration and idea exploration.
- **Consumer education and awareness building.** Lighting Africa/Global promotes the integration of consumer education and awareness building into projects to build demand. The focus of this awareness building has evolved from a general introduction to off-grid solar technology to helping consumers and financial backers identify quality products, learn of the applications now powered by off-grid solar, and identify financing opportunities.
- **Policy engagement.** Through research, hands-on lessons learned, and exchange with partners, Lighting Africa/Global has identified market bottlenecks and identified approaches to unlock market potential. Market conditions can be improved through policies and regulations, fiscal incentives, access to finance, adoption of quality standards, and consumer protection.

(*continues*)

BOX 4.1 (*Continued*)

- **Quality assurance.** To safeguard investments and ensure impacts while instilling confidence in consumers and financial intermediaries, Lighting Africa/Global developed quality standards for off-grid solar products, which have been adopted by the International Electrotechnical Commission as a reference for quality assurance and inform policy for more than 20 governments. The purchaser obtains dealer-backed warranties. Since February 2020, VeraSol has continued Lighting Global's Quality Assurance work, maintaining an updated list of quality-verified products.
- **Access to finance.** Financial constraints continue to be significant challenges as importers, retailers, and distributors need significant working capital. Consumers also need financing particularly for larger appliances such as those for productive use in agriculture. Lighting Africa/Global supports both supply-side and end-user financing through financial instruments including lines of credits, results-based financing, and end-user subsidies to expand access.
- **Capacity building.** As a fairly new and still developing sector, Lighting Africa/Global has helped improve government capacity in public sector energy access agencies, besides providing key business support.

Source: Lighting Global website: https://www.lightingglobal.org/.

Business/Operational Models

This section provides insights into the main emerging business model innovations that could be applied in sustainable cooling applicable for rural areas. It also provides a high-level overview of the financing mechanisms and support services that enable these models to work.

Across the three focus areas (i.e., space cooling, agricultural, and health care), technological advances and innovative business models for providing off-grid electricity and cooling access are beginning to demonstrate how access to both services can be accelerated in rural communities. Many of these models can apply equally to private, public, or joint initiatives. One common approach is for the public sector to create an enabling environment and facilitate access to finance and for the private sector to implement. The service providers/operators have been found to be almost exclusively from the private sector, even if under contract to the public sector. The private sector has demonstrated considerable innovation and initiative in addressing key challenges surrounding affordability/high up-front costs and adequate consumer protection (quality control, maintenance, warranties, after-sales service, etc.). The most promising business models all aim to foster market growth, through commercially viable, socially conscious activities that encourage sustainability.

Among the challenges to accessing energy and cooling services in rural areas, affordability for the end user is often the most significant, since cooling interventions typically add another cost to energy access or infrastructure, which itself is a significant financial burden. This is being addressed by various market models, which are discussed in the remainder of this section. All these models serve to reduce up-front costs to the end user by spreading payment over a longer term or shifting asset ownership to distributors/operators or to a third party, which then charges end users a fee for a service. While these models streamline maintenance and performance monitoring, and increase economies of scale, they also pose financing challenges to operators as assets remain on operators' balance sheets until fully paid off. New innovations such as the creation of special purpose vehicles have proven helpful in the decentralized solar systems space as business innovations that enable investors or third parties to own assets, make investments, and take the associated risks and share in the profits, while sales, service, and operation are handled by the operator/distributor of the cooling and energy equipment or services.

There are three broad categories of business models for selling, servicing, and maintaining stand-alone individual "appliances" such as fans, refrigerators, freezers, ice makers, and milk chillers on the one hand and larger walk-in cold storage rooms or "facilities" on the other. Financing for these appliances and solutions could be tailored based on whether a consumer is an individual or a business/operator:

1. **Direct purchase from retailers or utilities.** Products are typically procured directly by customers or donated to operators or end users, on an individual or bulk basis.
2. **Asset finance/leasing model.** End users enter into an agreement that lets them "own" a cold storage asset under a legal agreement once they make sufficient payments. In some countries, this is also known as hire/purchase, especially for domestic consumers. The pay-as-you-go (PAYG) model has become the best known of these "rent/lease to own" models, although there exist promising models such as on-wage financing and on-bill financing.
3. **Energy access or cooling as a service (CaaS).** An owner/operator owns a cooling asset while the end user pays for the services delivered by the asset. The fees paid over time cover the costs of the investment (including financing costs) and operating the asset and provide a profit margin. In the event of a failure to pay, the owner/operator restricts the end users' access to the asset. For assets such as walk-in cold storage facilities, a single asset could be used to service multiple consumers. Some PAYG agreements may actually be service agreements, where the end user never owns the asset and only pays for its use.

Many of these business model innovations have been demonstrated in well-established, higher-income markets, but not yet deployed to the same extent in low-income, rural areas, where gaps in cooling access are most acute, due to the low commercial attractiveness of these markets without the development of incentives. For example, the Basel Agency for Sustainable Energy (BASE) has championed CaaS, which has been adopted in high-value cooling markets, for example, commercial crop production for export. Conversely, PAYG and regular asset financing are the two prominent business/financing models used for the sale of the majority of cold storage equipment and cooling appliances (such as fans and refrigerators) accessible to rural users. These equipment and appliances are almost always sold by some form of a distributed energy service company, which also sells the solar power equipment to independently power the appliances. However, these approaches are at a nascent stage of development and often focus on poor customers who are hard to reach and have limited access to even basic infrastructure such as roads, water, educational, and health care resources. Therefore, developing these markets and providing access to these cooling resources require some form of government or donor subsidy (Efficiency for Access 2023b).

The discussion now turns to business models for the provision of sustainable cooling solutions in the three main areas of demand for cooling services in off-grid areas: space cooling, agriculture, and health care.

Space-Cooling-Focused Business Models

While little has been done to date, there is significant potential for promoting passive cooling innovations in rural areas before active cooling measures, which require electricity, are considered. Traditional passive cooling measures such as adequate ventilation, abundant shading in areas surrounding buildings, and building designs incorporating interior patios have been used in many rural areas. These are the first measures that should be supported—where rural poverty deters their adoption—to enhance the thermal comfort and safety of rural people, especially amid increasing cooling challenges due to climate change. Additional modern passive measures include cool roofs (painting roofs white), which have received negligible funding support despite proving to reduce indoor temperatures by up to 5°C without using electricity. Promotion of passive cooling appears ripe for advocacy by organizations seeking to increase vulnerable people's resilience to climate shocks and heat, as well as for consideration within Nationally Determined Contributions (NDCs) to the Paris Agreement, national cooling action plans (NCAPs), and changes to building codes and practices. This could result in cool roofs being included in residential and commercial buildings. These traditional measures could also be promoted retroactively not just for institutions but also among communities, with small incentives. This could yield transformative immediate results while also providing the initial drive to kick-start commercial local markets in this area.

Since fans are the most affordable and lowest-power-consumption cooling appliances, they are the most widely applicable cooling solution for homes, places of work, schools, and health care facilities in rural off-grid areas. Commercial markets for fans powered by off-grid solar are in early stages but growing fast, especially in rural homes and microenterprises. The required size for a fan is determined by the underlying climate conditions, affordability, electricity access, and supply from distributors. Data from the Global Off-Grid Lighting Association (GOGLA n.d.) indicated that affiliates sold 1.08 million fans worldwide in 2022; the estimated total global sales were 2–3 million units, of which 1–1.5 million were in off-grid areas.

Evaporative air chillers are emerging as commercial solutions in urban areas of Asian countries that have the right mix of climate conditions, low-cost local manufacturing, and sufficient national demand (such as India and Pakistan). They provide a higher level of cooling than fans and have high potential, although they are not widely used due to lack of rural availability and scant awareness among rural dwellers. The high cost and power requirements of air conditioners make them impracticable for rural off-grid consumers. Their adoption by these consumers is unlikely until there is a major technical shift that makes them more affordable.

The only currently widespread business model for rural space cooling is the sale and service of low-consumption/high-performance direct current (DC) fans bundled with stand-alone solar energy kits or their sale alone to their users as upgrades. Fans appropriate for off-grid use are sold either on a direct cash purchase basis by solar or electrical goods retailers (most typical in Asia) or by specialized last-mile solar equipment distributors and distributed energy service companies (DESCOs) often on a lease-to-own or PAYG basis (most typical in Sub-Saharan Africa). To make off-grid rural space cooling solutions affordable, they likely will need some form of expanded public support akin to that provided to solar home kits, which have often required direct subsidies to consumers to reach the most vulnerable, and to sellers to support the early development of commercial markets (see Box 4.2).

BOX 4.2

COOLING WITH SOLAR COMES TO RURAL HOMES IN PAKISTAN

In rural Pakistan, overall access levels are high, but electricity infrastructure is inadequate and electricity shortages remain frequent. Rural residents are increasingly turning to solar power as a viable alternative to unreliable and expensive grid electricity. Climate conditions also make space cooling in homes and microenterprises essential for a healthy environment, especially during the summer monsoons.

The Sindh Solar Energy Project aims to increase electricity access in the Sindh province by providing affordable and reliable off-grid solar home systems (SHSs) to 200,000 households. To create a sustainable market for high-quality SHSs, the program quickly identified a need to include a high-efficiency fan in the SHS bundle to meet end users' demands for cooling. The program required SHSs to be verified by the World Bank–funded VeraSol quality assurance program and for fans to meet the performance benchmarks developed by the sister Global LEAP program, assuring reliable performance of both.

Using solar to power fans. *Source:* Sindh Solar Energy Power Project, feasibility study, World Bank.

Besides quality assurance, the program design facilitates cost-effective imports through bulk procurement, and a network of Last Mile Distributors has been established to reach rural consumers. The inclusion of efficient DC fans in the SHS kits allows households to better utilize solar energy, making the project's offerings more practical and relevant for the target population. By providing cooling solutions alongside electricity access, the project aims to improve the overall quality of life for households in Sindh and make the solar systems more sustainable.

Note: See Appendix A for more information.

Agriculture-Focused Business Models

Overall, the development of rural cold storage for agriculture, dairy, fisheries, and livestock produce is in its nascency in emerging markets. The most prevalent business models and financing mechanisms apply to both (1) stand-alone refrigerator and freezer "appliances," and (2) walk-in cold room "facilities." Refrigerators and freezers appropriate for off-grid use (DC powered) have a power demand (100–1,500 Wp) that can be met using distributed renewables such as solar energy kits. Their retail price ranges from US$300 to US$5,000 depending on factors such as size, distance from the manufacturing location, and import and sales taxes. The productive use of these appliances for the temporary storage and sale of fish, milk products, and other retail products by micro, small, and medium enterprises and the like has been shown to cover the cost of investing in these appliances within months and at most one to two years, as long as the underlying business is commercially viable (Efficiency for Access 2023c). Larger "facilities" such as walk-in cold storage rooms have higher power requirements (minimum 1,500 Wp and typically 3,000–10,000 Wp). The smallest systems located in manufacturing hubs like India often require investments of at least US$20,000. Investments typically grow to approximately US$30,000–50,000 per 10 cubic meters of a walk-in cold room in Sub-Saharan Africa (including import of components, transport, taxes, and installation of the cold room and its power system) (Efficiency for Access 2021a).

As noted earlier, there are three broad categories of business models for selling, servicing, and maintaining stand-alone individual "appliances," such as refrigerators, freezers, ice makers, and milk chillers on the one hand and larger walk-in cold storage rooms or "facilities" on the other used in agriculture Table 4.1 illustrates some of the main advantages and challenges of one of the approaches for providing cooling appliances and facilities for agriculture and other related activities in rural areas—the CaaS model.

Supporting cold chains that boost farm income and support nutrition remains a challenging task. This begins, but by no means ends, with finding suitable financing tools to make funds available for deploying technical solutions suitable for farming communities. An appropriate financing mechanism must consider an equitable financial return to all stakeholders, from suppliers, operators, and end users, while minimizing the vulnerability of small holder farmers to climate or environmental conditions beyond their control (SEforALL 2020c).

Under CaaS- and ESCO-type models, maintaining adequate working capital for business growth presents a constant challenge. As detailed previously, it is rare to see solar fridges or freezers and their power supply retail for under US$1,200 in Sub-Saharan Africa, whereas even small walk-in cold rooms of 10 square meters typically cost over US$30,000. Holding substantial stock is thus very costly and represents a major working capital challenge for distributors or operators, especially under business models where these assets remain on a company's balance sheet for an extended period (Efficiency for Access 2021a).

Despite their similarities, the business models for appliances and cold rooms have one major difference: walk-in cold rooms/facilities are increasingly being seen as infrastructure, with the growing consideration that they may be best financed using long-term patient capital, under some form of informal or formal public-private partnership, which might then be able to attract different types of concessional finance.

TABLE 4.1

Advantages and Challenges of the CaaS Model

ADVANTAGES	CHALLENGES
1. Cooling as a service (CaaS) inherently fosters efficient and economical products. Service providers stand to grow profits by reducing the energy consumption of cooling devices and their up-front cost. Users are incentivized to pursue efficiency as monthly payments or bills reflect usage and an opportunity to conserve energy. 2. CaaS encourages environmentally safe disposal and recycling. Recycling machines help reduce operational costs for businesses, which can transfer reusable components to other systems. This is useful because, even with the e-Waste Management Rules 2016, there remain loopholes that manufacturers can exploit to evade their responsibilities, and the methods followed by recyclers are not always adequate. 3. CaaS can reduce the expense due to the maintenance and repair of cooling or refrigeration products in rural markets with restricted access to servicing infrastructure. 4. CaaS is a market-based model, which can be deployed independent of regulatory support once owners understand the benefits and investors grasp the returns. 5. Lenders and investors can turn fixed assets into continuous revenue streams as business grows through securitization.	1. The payback for investors could be long since substantial up-front investment is required to procure and service cooling systems. This strains the finances of businesses. Innovative financing could thus be necessary; for example, special purpose vehicles could be used to support companies in undertaking off–balance sheet financing (which has proven highly effective in financing the costs of solar home systems sold on a pay-as-you-go basis in the off-grid solar sector). 2. CaaS requires extensive service networks developed in-house or with third parties. This can consume substantial resources—more so in remote areas. 3. There is a high risk of payment default by low-income consumers. This is a challenge considering the complexity of risk guarantee instruments and their scarcity for energy efficiency projects and end users with low paying capacity. 4. Cultural resistance to the concept of buying services can adversely affect demand. For consumers who/that are accustomed to asset ownership (e.g., India), switching to alternate models can be difficult.

Source: Nain and Bhasin 2022.

Healthcare-Focused Business Models

The unprecedented nature of the COVID-19 pandemic highlighted the importance, and failures, of energy and cooling (cold chains) in ensuring vaccine transportation and storage at appropriate temperatures.

One significant response has been to increase funding for stand-alone solar-powered critical equipment such as vaccine refrigerators, which can then ensure cold chains reach off-the-grid populations through decentralized health clinics and vaccination centers. Solar direct drive refrigerators, since they started been implemented in 2014, have been widely used to deploy vaccines and serve other health needs in rural areas, in an effort to replace less reliable absorption-based refrigerators (WHO 2017).

Powering an entire clinic that is off the grid requires a much larger, more complex, and expensive power system (typically solar). Extending cooling into space cooling for a clinic's patients requires powering the entire clinic, including at least powering fans, providing power for lighting, medical equipment, and computer and communications equipment. The initiative to power vaccine cold chains that resulted from COVID-19 has expanded into programs for the sustainable electrification of health care facilities, for benefits beyond critical cooling load (see Box 4.3). This initiative is being undertaken through collaboration by a small variety of stakeholders such as the World Bank/ESMAP, SEforALL (Sustainable Energy for All), United Nations Children's Fund (UNICEF), the World Health Organization (WHO), and the Global Alliance for Vaccination and Immunization (GAVI). Where health care facilities have been electrified in this manner, most public institution electrification projects have been funded by grants and donor-supported initiatives focusing primarily on the procurement of solar photovoltaic (PV) assets.

BOX 4.3

SOLAR SYSTEMS AND REFRIGERATORS TO IMPROVE HEALTHCARE IN SOUTH SUDAN

The World Bank–financed COVID-19 Emergency Response and Health Systems Strengthening Project supports health service delivery in three states in South Sudan. The project objectives are to prevent, detect, and respond to the threat posed by COVID-19 and increase access to an essential package of health and nutrition services.

As of June 14, 2023, the project had installed 70 solar direct drive (SDD) refrigerators and four solar power systems. Further, project financing has helped procure eight sets of spare parts for the SDD refrigerators, 72 refrigerator loggers, and 805 cold boxes and vaccine carriers. An additional US$1.5 million has been provided for installing SDD refrigerators and solar power systems. This funding is based on the success of the original Energy Sector Management Assistance Program (ESMAP) grant.

The expansion of the cold chain infrastructure has been fundamental for reaching COVID-19 vaccination targets. It has enabled vaccinating 67 percent of the target population, one of the highest COVID-19 vaccination rates in East Africa. This expansion is also anticipated to support the expansion of basic childhood immunization, which currently is at the low rate of 11.5 percent of children (complete case study in Appendix A).

Source: World Bank 2023.

The focus on solar system and vaccine refrigerator procurement has led to a predominance of "equipment ownership" models. Further, the generally short project schedules have led to prompt payment and rapid deployment being prioritized over long-term operation and maintenance planning. Such a strategy may jeopardize the long-term viability of solar PV systems since it prioritizes asset acquisition over service provision and performance. The ESCO or the "energy as a service model" has emerged to address both sustainability and scalability. This service model represents an opportunity for a new set of stakeholders—primarily from the private sector—to assume an expanded role in energy service delivery to public institutions. It also changes the payment dynamics for electricity, shifting from energy asset procurement to paying for sustainable energy services. In this way, it can be seen as a mirror to the CaaS model for the provision of agricultural cold chain facilities.

This ESCO model is one potential way to mitigate sustainability risks. For example, a government selects an electricity services provider (for installing and operating PV systems) to serve public institutions, typically over 10–15 years. Service providers can be selected through competitive means, including auctions, issuance of concessions, or general tenders. Each service provider is responsible for raising investment capital and ensuring that key performance indicators are met during the contract period. The government pays the providers regularly, as it would other utilities.

The service-based delivery model promotes sustainability because the private sector—with its expertise and technologies—can deliver long-term quality services aligned with the asset's lifetime. This approach relieves the government of the burden of raising the full up-front investment needed for energy assets, even though it must allocate an adequate and consistent budget to ensure public institutions can make regular payments to service providers over time (SEforALL and ESMAP 2021).

The public-private global health partnership GAVI considers innovative technology crucial for extending the cold chain to ensure life-saving vaccines reach remote off-grid communities. In poorer countries, which rarely have markets and delivery mechanisms for new technologies, governments and health partners must use their limited resources to purchase and maintain cold chain equipment (GAVI 2018). Innovative financing mechanisms, therefore, become essential, perhaps mobilizing climate finance windows, to attract commercial service providers into the market. GAVI's core partners, UNICEF and WHO, have placed bulk procurement orders representing approximately 90 percent of the global market for solar-powered vaccine refrigerators. Similarly, most off-grid rural clinics and even schools could purchase cooling equipment under regional or national bulk procurement models.

Overall Summary of Emerging Business/Operation Models for Off-Grid Cooling

Table 4.2 summarizes the different business models discussed, while Appendix B elaborates on the models outlined in the table and provides real-world examples of their use in the applicable sectors. Details are also given in Appendix A, which also provides examples from the real world.

TABLE 4.2

Summary of Business Models for Off-Grid Cooling

BUSINESS MODEL	FEATURES AND SECTORAL USAGE	OWNERSHIP
Direct Purchase	A customer acquires cooling equipment from a seller upon full payment. Or, an intermediary may pay for the equipment and donate it to end users or groups (e.g., farmer producer cooperatives). Service and maintenance must not be forgotten in this case. **Sector.** Residential space cooling, storage and space cooling for health care, and agriculture (micro, small, and medium enterprises)—although the typically high prices severely restrict widespread adoption	A single end user, customer, or an organization serving multiple end users.
Pay-As-You-Go (PAYG)	Customer purchases a cooling appliance/service and pays over time, with a small extra payment. Popular model for off-grid solar. Customers either own a product when paid in full or continue paying for the "service" from using that product in perpetuity. **Sector.** Microenterprise cold storage productive use appliances (refrigerators and freezers) in agriculture and retail for farmers, households, and microenterprises. Consumer space cooling appliances such as fans bundled with solar system kits or as upgrades by distributors. Financing by the seller/operator that needs access to low-interest/long-term loans to match payment profile of low-income users.	If "lease/rent to own," the end user owns the appliance once payment is complete. If not, then the appliance is owned by the service provider.
Cooling as a Service (CaaS)	A cooling service provider delivers refrigeration services in return for a fee based on the customer's usage. The service provider invests in infrastructure and is responsible for maintenance and operation. **Sector.** Ideally for private or public-private partnership arrangements. In the agricultural sector, it is used by market traders to store produce overnight in walk-in cold rooms. Under consideration in the health sector but not widely adopted (vaccine, medicine storage). Financing carried by the operator, which needs access to low-interest/long-term loans to match the payment profile for low-income users or government beneficiaries.	Service provider
On-Bill Financing	A seller provides services/sells products to a customer against a utility bill as the repayment vehicle. This model is commonly used by on-/off-grid energy service providers. Works best when a cooperative or commercial body extends the service to employees or cooperative members. **Sector.** Space cooling, agriculture storage, and health care facilities. Financing carried by the operator, access to low-interest/long-tenure loans will be needed to match the payment profile for low-income users or government beneficiaries.	Shifts from seller to buyer, often with risk underwritten by an intermediary (such as a cooperative or utility).
Dealer Financing and Leasing	A financial institution funds a cooling service enterprise through a finance leasing agreement, with the cooling system used as collateral. **Sector.** Suitable for space cooling, agriculture, and health facilities. Assets still require financing, which shifts to the dealer, which needs access to low-interest/long-tenure loans to match the payment profile for low-income users or government beneficiaries.	Financier/service provider during the lease. Following full repayment, ownership may be transferred to the end user.
Energy Service Companies (ESCOs)	A third party (e.g., a private or public financier or even a development finance institution) invests directly through an ESCO, which enters into an energy performance contract with each end customer or client that guarantees energy and monetary savings. The ESCO repays the full amount to the financier. The ESCO model is more applicable for more advanced markets. **Sector.** Agriculture and health sectors, although usually for large enterprises. Financing needs are carried by the operator, and access to low-interest/long-term loans will be needed to match the payment profile for low-income users or government beneficiaries.	The ESCO, shifting to the client when the ESCO contract ends or by mutual agreement, after full repayment by the ESCO to the financier.
Community Cooling Hubs	This model aggregates demand and creates ownership among the targeted end users through a community-based operation. These cooling solutions—selected as "game-changing solutions" for the 2021 United Nations Food Systems Summit—serve as hubs for agriculture cold storage and can in principle serve a broader variety of cooling needs, for example, vaccine storage or protection during heat waves. Management by a community requires a level of organizational and human resource capacity, which may not be widely available. **Sector.** Suited for agriculture storage and potentially for medical cold storage. The resources required to better understand potential suitability include the Cool Coalition NCAP data framework for agriculture, the SEforALL Cooling Needs Assessment, and the Africa Centre for Sustainable Cooling and Cold-Chain.	Service provider that is a community group.

Note: NCAP = national cooling action plan; SEforALL = Sustainable Energy for All.

Importantly, gender-sensitive design should be considered to ensure women and men can equally participate in and benefit from any financing solution and business model. For instance, in Odisha, India, the "Your Virtual Cold Chain Assistant (VCCA)" program, launched by the BASE Foundation and Empa, reduced post-harvest losses and increased income for both male and female farmers. "Your VCCA" partners with local technology providers running solar-powered cold rooms on a CaaS business model and uses the Coldtivate app to streamline operations. After a baseline study showed that women famers are less likely to own a regular phone or a smartphone, and have lower literacy rates, efforts were made to ensure equitable access to the service for both male and female farmers: cold room operators were trained to inform farmers without personal phones about the remaining storage life of their crops, and all awareness-raising efforts used pictorial messages, local languages, and peer-to-peer learning (BASE and SEforALL 2023).

Financing for Expanding Access to Cooling

The financing landscape for expanding cooling access is complex. Each stakeholder across the value chain (equipment suppliers, distributors, operators, customers, and intermediaries) has distinct financing needs, which usually require distinct funding mechanisms. These financing needs and mechanisms vary not just across the application areas of space cooling, agriculture, and health care, but also according to the common factors that are applicable to each sector, for example, market maturity, macroeconomic conditions, and political and fiscal environment.

Public sector project development and investments in electricity access are typically supported by concessional national or international public financing mechanisms. Viewing cooling/electricity from a nexus perspective reveals the potential to open more possible finance windows if cooling and electricity are considered together rather than as stand-alone projects.

There is considerable overlap between the experience with financing for access to energy and access to cooling. Although these nexus areas are still largely in early stages of development, there are growing examples where business and financial cases are being shown to hold potential to be commercially viable. Nevertheless, challenges remain with increasing the awareness of the cooling technologies in the marketplace, making equipment more affordable, and increasing the scale of adoption especially given the low incomes of the people in off-grid areas.

Funding instruments to help meet cooling needs will evolve as technologies and business models develop and stabilize (SEforALL 2022a). Overall, significant financing gaps remain, notably in the agricultural and health sectors, and for passive cooling and building design. There is also a risk of finance continuing to favor higher-income, urban markets, since cooling challenges are more diverse in rural areas, especially in off-grid rural areas, where residents have lower financial capacity. Public energy financing programs to electrify underserved communities could include off-grid rural cooling solutions, which would require combining public financing and subsidies with private delivery of services given the low incomes in off-grid areas. Factors to be considered in planning interventions could include, among others, the institutional capacity of the government agency, potential partners, insights on potential markets, market development stage, consumer profile, and probable risks in all stages of program implementation.

Public and Blended Finance Mechanism

Given the nascent market for rural cooling and the many benefits of increased cooling access, blended finance could support the off-grid cooling sector's development and accelerate growth (Convergence n.d.). Blended finance through development banks has proven helpful in launching high-risk initiatives with potential for beneficial and quantifiable social and environmental outcomes in regions in severe need, including fragile and conflict-affected situations (Hatashima and Demberel 2020). While multiple climate projects supporting energy-efficient appliances have proven attractive for blended finance—due to their commercial technologies and long-term cost savings—[1]achieving similar leverage for access to cooling in rural areas remains a challenge given the uncertain profitability of off-grid cooling, and the lack of affordability.

Box 4.4 provides an overview of the public financing instruments that have been leveraged for off-grid solar electrification, over a decade of private sector led development driven by the International Finance Corporation, ESMAP, and the World Bank's Lighting Africa and Lighting Global initiatives. Many of these instruments can be applied for off-grid cooling, given the similarities between the two markets and the overlap of many product suppliers and distributors or distributed energy service companies/ESCOs distributing solar kits and high-performance cooling appliances for off-grid solar-powered space cooling and agricultural cold storage. Most mechanisms available are geared toward addressing supply-side constraints to encourage business development and innovation. Thus, they enable competition and cost reduction while creating a conducive market environment and eventually reducing market prices (ESMAP 2022). The mechanism most commonly used so far in the cooling sector is results-based financing.

Results-based financing is centered around the disbursement of donor funding to an implementing party (e.g., a product distributor or service provider) based on a third-party-verified performance or "service delivery" against agreed-upon metrics (World Bank 2019). The quality of the incentive's design determines the effectiveness of this type of public finance. Under results-based financing, program implementors (typically private companies) are motivated to maximize efficiency and deliver high-quality output at speed and scale while taking on the risk of output delivery. Although this instrument has proven to achieve development outcomes and accelerate innovations across sectors (World Bank 2019), its use for sustainable off-grid cooling is nascent and limited to the sale of cooling appliances supported by a growing number of donors and delivery partners. (See Box 4.5).

BOX 4.4

PUBLIC FUNDING MECHANISMS FOR OFF-GRID—APPLICABLE TO OFF-GRID COOLING

Up-Front Grants

- Nascent markets.
- Young and innovative companies.
- Companies lacking a track record for attracting investment.
- Established companies must be incentivized to enter new markets.

Results-Based Financing

- High costs or risks are preventing companies from entering underserved geographies, although they are already operating in nearby areas.
- There is a need to rapidly scale up the number of people reached or the geographical area served by existing off-grid solar (OGS) companies.

Tax Exemptions

- OGS has political support, and market growth is a government priority.
- Affordability is a major growth barrier.
- Quality-verified OGS must be promoted.
- Revenue and customs authorities are willing and/or able to implement quality-linked tax exemptions.
- If introduced, tax exemptions can be trusted to remain in place for a reasonable length of time.

Credit Lines

- Companies require working capital and are close to being able to meet lenders' requirements.
- Domestic financial sector is close to being willing and able to lend to the OGS.
- Financial institutions have liquidity but are reluctant to lend due to perceived risks.

(*continues*)

BOX 4.4 (*Continued*)

Risk Mitigation Instruments

- Financial institutions lack experience of lending to OGS.
- Financial institutions are unable to accept OGS assets such as receivables as collateral.
- Bank systems and processes or regulatory requirements disincentivize lending to OGS companies.

Demand-Side Subsidy

- Households are unable to afford OGS products.
- Supply-side mechanisms to address affordability are either not feasible or are already being implemented, despite a persistent affordability challenge.

Bulk Procurement

- A public or private institution aggregates the demand for a cooling device and places a bulk order.
- This creates economies of scale, reducing the unit price and making after-sales maintenance more attractive to suppliers.
- The devices are made available to users—e.g, the health ministry distributes solar vaccine refrigerators to health clinics.

Source: Lighting Global and ESMAP 2022.

As noted earlier**, bulk procurement of sustainable cooling solutions** involves a public (or private) institution aggregating the demand for a cooling device (such as a fan, refrigerator or even walk-in cold room) and placing a bulk order. This large guaranteed order enables investment and production at volumes that deliver economies of scale. It also encourages the scaling of operations, service and maintenance to be more attractive for suppliers and encourage their commercially viable functioning. Clear opportunities for this already exist, as evidenced by the vaccine cold chain sector, where GAVI is organizing bulk procurements. GAVI's core partners UNICEF and WHO have placed bulk procurement orders representing approximately 90 percent of the global market for solar-powered vaccine refrigerators.

BOX 4.5

INNOVATIVE FINANCING AT CLASP—RESULTS-BASED FINANCING FOR SUSTAINABLE COOLING SOLUTIONS

Financing mechanisms for cooling in under-electrified settings hold significant potential to improve quality of life and economic productivity, but they have not yet been widely tested at scale. The Productive Use Appliance Financing Facility has been funded by the Global Energy Alliance for People and Planet (GEAPP), while developed and delivered by the Collaborative Labeling and Appliance Standards Program (CLASP) and Nithio (which was announced in October 2022).

The facility aims to catalyze the uptake of six types of productive use appliances in Africa that could multiply the development impact. These include three appliances that support cooling: walk-in cold rooms, refrigerators/freezers, and fans. During the first round of results-based financing, US$1.5 million was allocated to support the sale of 4,000 solar-powered fridges and 73 walk-in cold rooms.

This Facility provides funding to companies operating in the Democratic Republic of Congo, Ethiopia, Kenya, Nigeria, Sierra Leone, and Uganda. It will offer a range of support, for example, through capacity building grants, product testing and benchmarking, procurement subsidies, matchmaking, and concessional debt.

The goal is to address the most challenging aspects of deploying high-efficiency, sustainable cooling technologies: affordability and high first cost. For example, the cost of a quality-assured (based on VeraSol criteria) off-grid refrigerator is approximately 85 percent of the average Kenyan's household income—making it prohibitively expensive despite the clear benefits. In a survey of 1,502 off-grid refrigeration customers in Kenya, Tanzania, and Uganda, 37 percent of the respondents reported a "very much improved" quality of life and 79 percent reported using their off-grid refrigerators for income-generating activities (Efficiency for Access and 60 Decibels 2022).

The Productive Use Appliance Financing Facility aims at greater affordability through direct unit cost reductions—which will be achieved by driving initial economies of scale on the supply side—and by making it easier for appliance distributors to offer consumer financing. In many cases, technological innovation in cooling is more immediately accessible for grid-connected and higher-income consumers. There is a pressing need to broaden the range of affordable solutions for rural and low-income consumers. This Facility is demonstrating progress in supporting the uptake of cooling appliances, although more pro-rural innovation and finance are needed to deploy renewable-energy-based cooling technologies and applications along the food, health, and building value chains in rural, off-grid locations.

Source: Efficiency for Access and 60 Decibels 2022; CLASP 2023.

Similarly, most off-grid rural clinics and even schools could purchase cooling equipment under regional or national bulk procurement models. The same could also be done for walk-in cold rooms purchased as public infrastructure, either at aggregation points (e.g., among farmer producer organizations) or in municipal markets for retail or wholesale (which could be operated either to provide CaaS to farmers or traders or as publicly owned assets with operation and maintenance provided under contract by the installer or by a third party if necessary and incentivized suitably). As shown in the previous section on operational models, there are clear cases where cold chain facilities and equipment can be seen as a public good and where it can be most economically feasible for them to be purchased in bulk regionally or even nationally as part of public infrastructure investments. Similarly, bulk procurement by private operators can create economies of scale, in turn reducing the unit purchase price and making wholesale and after-sales maintenance systems more commercially attractive to equipment suppliers. Coca-Cola providing solar-powered refrigerators at its soft drinks franchise sales/distribution points could be an example of bulk procurement by private operators.

Climate Finance for Access to Cooling

Sustainable cooling contributes to both climate change mitigation and adaptation—especially in the rural context, which necessitates the use of higher-efficiency technologies alongside off-grid renewable electricity systems. It supports the mitigation agenda through reducing emissions of gases with high global warming potential and the reduction of emissions associated with food waste. Meanwhile, the adaptation agenda can be supported by solutions that help people and livestock cope with increasing heat stress. These open opportunities to access climate finance from different windows (see Appendix E for more information).

One of the first examples of major climate financing specifically for cooling access was the Green Climate Fund's commitment to provide US$157 million for a **new Cooling Facility** at the World Bank, with an additional US$722 million in leveraged co-finance from World Bank projects. The facility will support nine countries to develop low-carbon and inclusive cooling solutions and focus on space cooling, refrigeration, and cold chains. Other opportunities to finance cooling access initiatives include the **Global Environment Facility's** Least Developed Countries Fund and Special Climate Change Fund, and the **Climate Investment Fund's** (CIF's) US$1.2 billion **Pilot Program for Climate Resilience.** Synergies between funds can produce greater leverage, and the World Bank's Cooling Facility aims to identify such opportunities with the CIF to improve its impact. For example, where the CIF could address barriers to stand-alone solar technologies in rural settings, the Cooling Facility would focus on cooling solutions for productive uses. The most recent development in the efforts to mobilize financing for climate change has been the announcement of an agreement reached to operationalize a **Loss and Damage Fund**, which will help vulnerable nations offset damages due to the impact of climate change. The announcement was made at the UN Climate Change Conference (COP 28) on November 30, 2023. The fund will help those nations cope with the cost of the devastation caused by ever-increasing extreme weather events such as drought, floods, and rising sea levels.[2]

Climate finance to support rural climate mitigation and adaptation can also seek to leverage the electricity access–cooling access nexus. Table 4.3 below provides some examples of Climate Finance Facilities that support Sustainable Cooling. The **CIF's Scaling Up Renewable Energy Program in Low Income Countries** is one example of the utilization of climate finance to scale up renewable energy for expanding electricity access. The **World Bank's Distributed Access through Renewable Energy Scale-Up Platform (DARES)** (World Bank 2022a) and **Accelerating Sustainable and Clean Energy Access Transformation Program (ASCENT)** (World Bank 2023) aim to increase the productive use of sustainable cooling appliances in households and small-to-medium businesses and in the various agriculture, dairy, fisheries, and livestock sectors to help strengthen the business case for electrification.

TABLE 4.3

Examples of Climate Finance Facilities for Advancing Sustainable Cooling Access

INSTITUTION/PROGRAMME	LEAD PARTNER(S)	FINANCE	FOCUS OR SECTOR
Cooling Facility	ESMAP, World Bank and GCF	US$157 million, plus US$722 million in leverage	Climate change mitigation and adaptation
NDC Facility	CCC, implementing partners	US$12 million	Climate change—NDC focus
World Bank ESMAP Efficient and Clean Cooling Program	World Bank ESMAP	US$15 million	Technical assistance, awareness raising, knowledge creation
ACES	U4E, Government of Rwanda, and University of Birmingham, UK	US$6.8 million +	Technology, business models, and services to expand access to cooling in Africa
CaaS Alliance	BASE	~US$50 million in assets under a CaaS model (estimate)	Technology and business models
Climate-friendly agricultural cold chains in India	UNEP, CCC, AEEE, EESL	US$50 million mobilization target	Agricultural cold chains
Global Cooling Prize	Rocky Mountain Institute	Up to US$3 million	Prize for sustainable air conditioner technology demonstration
Million Cool Roofs Challenge	Global Cool Cities Alliance (GCCA), CCC, SEforALL	US$2 million	Prize for cool roof demonstration

Source: SEforALL 2022b.

Note: ACES = Africa Centre of Excellence for Sustainable Cooling and Cold-Chain; AEEE = Alliance for Energy Efficient Economy; BASE = Basel Agency for Sustainable Energy; CaaS = cooling as a service; EESL = Energy Efficiency Services Limited; ESMAP = Energy Sector Management Assistance Program; GCF = Green Climate Fund; NDC = Nationally Determined Contribution; SEforALL = Sustainable Energy for All; U4E = United for Efficiency; UNEP = United Nations Environment Programme.

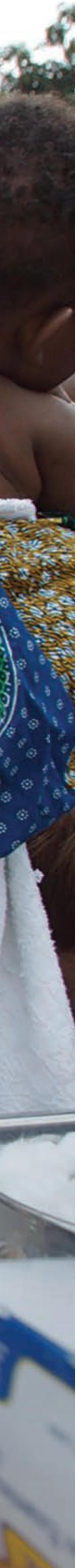
Carbon finance also represents an emerging opportunity to monetize the emission reduction benefits of sustainable cooling. Using voluntary or compliance-based carbon markets, carbon finance can raise substantial private capital for activities that remove or reduce greenhouse gas emissions, typically through technology interventions. As carbon markets continue to mature, sustainable cooling technologies such as hyper-efficient air conditioners, fans, and refrigerators, as well as nature-based passive cooling solutions, offer potentially bankable carbon finance investments.

Endnotes

1. See, for example, a Green Climate Fund project promoting energy-efficient equipment in El Salvador through an insurance scheme developed by the Inter-American Development Bank (GCF 2016).
2. The draft agreement to operationalize this fund aims to help compensate vulnerable nations for the impact of climate change by, for instance, ensuring that vital infrastructure can be rebuilt or replaced with more sustainable versions. Countries reportedly making contributions include the United Arab Emirates, Germany, the United Kingdom, and Japan (UN News 2023).

FIVE

POLICIES AND ENABLING ENVIRONMENT FOR COOLING IN RURAL OFF-GRID AREAS



Enabling greater rural off-grid access to sustainable and efficient cooling services requires policies to frame and guide activities at the program, project, and activity level, as well as the creation of an enabling environment to support these efforts. This chapter has two sections. The first section discusses policies. Since cooling services are needed in many sectors of the economy, integrating cooling policies and programs into national, economic, and sectoral policies is as important as cooling policies themselves. The section discusses the integration of cooling into electrification planning, economic and sector development policies, climate action plans, and national cooling action plans (NCAPs). The second section discusses the elements of an enabling environment for increasing access to off-grid sustainable cooling including regulations, standards, and quality assurance; concessional financing for equipment suppliers and end-user finance; public awareness and behavioral change; capacity building and training; and data tracking and reporting.

Across all areas, supporting policies and enabling activities should include gender considerations to avoid perpetuating existing disparities. The extent to which gender considerations are included in cooling policies, depends on the institutional requirements established for these considerations, the gender makeup of those leading policies' development, and the availability of sex-disaggregated data. Moving ahead, incorporating gender-based analyses into policy development and implementation, both at the national and local level, is a valuable approach to identify the cooling needs of women and men and ensure that they equally participate in and benefit from initiatives (SEforALL 2021c).

Supporting Policies for Cooling and Their Integration into Other National Policies

Integrating Cooling and Electrification/Energy Planning

National electrification strategies and least-cost electrification planning can be powerful policy tools that can help integrate access to cooling alongside energy access in countries with energy access gaps. The World Bank has helped to complete least-cost electrification plans for a number of countries (World Bank 2020a).

Integrated energy plans contain much information that is highly relevant to activities promoting access to cooling in rural off-grid areas. Today's integrated electrification plans generally aim to provide electricity services to all households; they plan to serve areas close to the grid (e.g., say within 2.5 kilometers [km]) via grid extension and densification. Areas at an intermediate distance from the grid (e.g., more than 2.5 km but less than 25 km) would be served in the medium term with off-grid solutions, while those at a greater distance would use off-grid services for the long term. Geospatial plans are often developed. These plans show the location of households and public facilities in relation to the grid. Areas to be served with off-grid solutions in the medium to long term would be those that require off-grid cooling solutions.[1]

Electrification planning is often preceded by household energy access surveys. This planning sometimes utilizes the Multi-Tier Framework (MTF), which is discussed in Section 3.2. Such surveys provide a wealth of information, including household characteristics, household members' gender, education level, income, assets (including appliances such as solar lighting kits and fans), and the structure of the home. Information is also often gathered on the characteristics and energy needs of small businesses and public buildings such as schools and health centers, and economic activities in the health and agriculture sectors. This information is equally useful for planning cooling interventions. Integrated energy plans also often include culturally and socially appropriate approaches to making off-grid energy solutions affordable to end users and available through appliance dealers; these approaches can also be applied to cooling equipment.

The inclusion of cooling needs in integrated energy plans can be an effective way to increase cooling access. This is a new frontier that is only beginning to be explored. Recent integrated energy plans in Malawi and Madagascar included the demand for vaccine refrigeration due to COVID-19, and led to the inclusion of dedicated cooling modules to meet the cooling and energy needs of a vaccine cold chain. In Malawi, a health facility needs assessment conducted as part of a recent integrated energy plan found that approximately US$21.2 million was needed for energy access and to build cold chain resilience across off-grid and grid-tied facilities; of this, only US$3.6 million is needed for 186 off-grid facilities (SEforALL 2022c). The World Bank is also piloting its Climate Friendly Cold Chain Tool in three countries to similarly understand energy and cooling needs, as well as emissions mitigation opportunities, for vaccine cold chains (see Box 5.1).

BOX 5.1

WORLD BANK CLIMATE-FRIENDLY COLD CHAIN TOOL

The World Bank's Energy Sector Management Assistance Program (ESMAP) team together with the Schatz Energy Research Center at Humboldt University developed the Climate Friendly Cold Chain Tool in response to the growing need to support developing countries in their vaccination endeavors through cold chain development and in meeting the related energy needs. The tool combines existing resources related to vaccine deployment, energy systems, and building efficiency to build climate-friendly scenarios for cold chain improvement along with related energy solutions. Using the tool requires demographic data, vaccine deployment strategies, data on the electricity access of health facilities, and estimates of existing cold storage. Recognizing the urgent need to deploy COVID-19 vaccines, the tool allowed users to customize outputs for this specific need. ESMAP is piloting this tool in three countries: Ethiopia, Nigeria, and Somalia. For Nigeria, ESMAP is working with Sustainable Energy for All (SEforALL) to advance this initiative.

The approach of using geo-spatial and survey data for electrification planning can be applied to determining the cooling needs, related off-grid energy system needs, and the related investment costs in off-grid rural areas for space cooling, agricultural and health cooling requirements. These can be determined based on the basic principles of the MTF, using data on the availability and costs of off-grid electricity systems (e.g., solar) and cooling appliances, and their efficiency.

Energy efficiency action plans are another common policy framework where sustainable cooling can be addressed meaningfully. Such strategies are typically developed in relation to achieving Sustainable Development Goal (SDG) target 7.3 of doubling the energy efficiency improvement rate, and they focus on energy efficiency and conservation policies such as performance standards and labels for appliances. Expanding their scope to include similar standards for off-grid cooling—across applications in homes; on farms; in micro, small, and medium enterprises; and in rural health clinics—can support increased access to sustainable cooling in rural settings while increasing the pace of rural electrification through higher efficiency standards.

Leveraging Economic and Sector Development Policies for Rural Cooling

Sustainable cooling is cross-sectoral and can be meaningfully incorporated into sector-specific plans and policies related to rural economic development, health care, and agriculture, and support accelerated achievement of many SDGs.

With economic development in rural areas typically lagging behind that in urban centers, countries experiencing a development gap often have a **rural economic development strategy** or a relevant ministry to advance progress. The contribution of sustainable cooling to achieving the SDGs is well documented (Peters 2017); among others, it supports improved nutrition, gender equality, and better livelihoods. Integrating cooling into rural economic development frameworks is thus an important area of opportunity.

Agriculture remains the dominant engine of rural economic development for many developing countries, which typically have **agricultural development plans or strategies** to guide the sector. Within such strategies, measures to strengthen agricultural value chains are commonly addressed, and access to cold storage and cold chain equipment are an important component of moving to higher value agricultural production and reducing food loss and waste, including in off-grid rural areas. For example, India set a target of doubling farmer's incomes between 2016 and 2022 and addressed cold chains as a tool to improve market access (Ministry of Agriculture & Farmers Welfare, India 2017).

Another development outcome linked to cooling, and where rural outcomes typically do not keep up with urban centers, is in immunization coverage in the health sector. While the number of children missing out on routine vaccinations has improved to near pre-pandemic levels (WHO 2023a), vaccination rates for rural children are lower than urban counterparts in Sub-Saharan Africa (Asmare, Madalicho, and Sorsa 2022; Adamu et al. 2019). Particularly in light of the COVID-19 pandemic, countries typically have a **strategic plan for regular immunizations** which include strengthening cold chains. Using these policies to increase the procurement standards for sustainable, energy-efficient vaccine cold chain equipment, including for rural off-grid areas, and to train a rural workforce on their operation are two opportunities among many in the health sector to improve rural cooling access.

Supporting Rural Cooling through Climate Action Policies

Sustainable cooling in general, and specifically in rural areas, is rightly considered a 'blind spot' for climate change mitigation and adaptation. For adaptation, cooling is especially important in off-grid rural areas, as unmet needs for space cooling already threaten health and productivity in homes, schools and indoor workplaces while warming temperatures and extreme heat will make these effects worse. For mitigation, there is a need to limit potential emissions associated with a rise in energy demand for cooling. As countries seek to implement the Paris Agreement on Climate Change and the Kigali Amendment to the Montreal Protocol, there are a number of climate action policies that could include rural cooling measures.

These include **Nationally Determined Contributions (NDCs) to the Paris Agreement**, which have been submitted to the United Nations Framework Convention on Climate Change. These documents typically set targets for mitigating greenhouse gas emissions that cause climate change, but also typically outline how countries plan to adapt to climate impacts, as well as support needed to achieve these goals. Sustainable cooling is increasingly being considered within NDCs, with an estimated 39 percent of countries including cooling in these documents (UNEP 2023).

Within their NDCs, countries have included sustainable cooling strategies as an adaptation action to support the fulfilment of their commitments, notably in the agriculture sector. Cambodia, in its 2020 NDC, included improved access to a sustainable agriculture cold chain for food security in vulnerable communities as a key adaptation action to increase the resilience of the agricultural sector. In South Sudan's NDC, the establishment of adequate cold storage solutions was identified as a circular opportunity for the agriculture, livestock, and fisheries sectors.

NDCs are typically broad, strategic documents highlighting a range of actions across multiple sectors. They are often complemented by thematic or sectoral plans that guide implementation in the country. **National adaptation plans (NAPs)**, initiated at the 16th United Nations Climate Change Conference (COP16), are one such mechanism to formulate adaptation strategies and prioritize their medium- to long-term implementation. Although 45 percent of countries have put forward NAPs addressing extreme heat and cooling (UNEP 2023), recent advances in the data, tools, and methods to support cooling access mean there is an opportunity to provide more granular details on the priority actions for human safety and well-being, agriculture, and health care. As climate funds such as the Green Climate Fund and the Global Environment Facility increasingly prioritize adaptation in their financing approaches, NAPs can be used as financing roadmaps for sustainable rural cooling, including for off-grid areas.

Supporting Cooling through National Cooling Action Plans

National Cooling Action Plans (NCAPs) can be useful tools to unify various measures and targets to deliver on national cooling objectives, including rural cooling. NCAPs support the implementation of the Kigali Amendment to the Montreal Protocol with holistic strategies to address the hydrofluorocarbon phasedown, energy efficiency, climate change, and the SDGs. Since an unmet and growing cooling demand is a cross-sector challenge, NCAPs can provide an effective and all-inclusive policy approach to make indispensable cooling accessible to all while targeting climate mitigation and adaptation goals. They can also provide critical support to coordination and cooperation among governments and stakeholders and have been endorsed by the UN Secretary-General for their role in delivering sustainable and life-saving cooling services. NCAPs typically focus on demand projections; markets; and the promotion of efficient space cooling, refrigeration, cold chains, and mobile air-conditioning. They can include sectoral energy demand and emission reduction targets; recommend policy frameworks for cooling appliances (e.g., minimum energy performance standards, MEPSs) and improved building energy codes; and increase consumers' awareness on energy efficiency to achieve energy goals.

Since 2018, when the first NCAP was publicly launched in India, 31 NCAPs have been established or are under development (UNFCCC 2023). The India Cooling Action Plan seeks to provide an integrated vision across sectors; this vision encompasses, *inter alia*, reduction of cooling demand, refrigerant transition, improving energy efficiency, and better technology alternatives over a 20-year time horizon. It provides short-, medium-, and long-term recommendations for different sectors, while providing linkages with various government programs for providing sustainable cooling and thermal comfort for all. An implementation framework is also set forth to coordinate the implementation of these recommendations (Ozone Cell 2019). Another notable NCAP is Rwanda's "National Cooling Strategy," which includes a specific reference to scaling up cold chain and off-grid cooling infrastructure (Ministry of Environment, UN Environment, and REMA 2019). Regardless of the development stage, these documents are useful in reflecting the political commitment necessary to influencing new strategies or in building upon previous strategies to link rural development, electricity access, and sustainable cooling.

To serve rural populations effectively, NCAPs must go beyond energy efficiency and the refrigerant transition, to consider how to improve access to sustainable, affordable cooling solutions and how action contributes to the SDGs. The Cool Coalition developed a holistic methodology to formulate NCAPs that emphasizes understanding cooling needs across multiple sectors and addresses them with an integrated approach, which first reduces the cooling needs, before servicing them with efficient equipment and system optimization (Cool Coalition et al. 2021). Disaggregation of gender-based data and preliminary assessments of the needs and roles of women and men should be used to strengthen NCAPs and facilitate tracking of gender-sensitive outcomes. For example, Trinidad and Tobago's NCAP requires incorporating gender into the market assessment for refrigeration and air-conditioning, while Cambodia's NCAP promotes women's participation in the decision-making process related to updating policies or amending regulations.

CROSS-SECTOR COORDINATION FOR SUSTAINABLE RURAL COOLING

As mentioned earlier, there is a plethora of strategic initiatives that address sustainable cooling. It is neither possible nor desirable to develop a single, all-encompassing strategy that covers not only NDCs, NCAPs, Kigali Implementation Plans (KIPs) and NAPs, but also rural development, agriculture, health care, and education strategies. However, ensuring that these initiatives are coordinated and not conflicting is a key priority. Since rural cooling is cross-cutting—e.g., across food and agriculture, health care, transport, energy, and climate—it requires interagency/ministerial coordination and cooperation on policy and program design and implementation from ministerial to operational levels. Mandating, funding, and incentivizing coordinated technical and bureaucratic support across government agencies/ministries is crucial for cooling to be successfully integrated in program design across governments.

Coordination groups could be responsible for the identification of cooling gaps.[2] Coordination among governments and other stakeholders is necessary to draft, update, and integrate cooling-related policy instruments. It is also needed to create opportunities for the adoption and promotion of efficient off-grid cooling appliances in rural communities;[3] fund research and development on off-grid cooling; promote energy efficiency for cooling appliances (e.g., through the application of MEPSs); and promote and operationalize best practices in region-specific cooling sectors.

The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES) is one attempt at bringing together diverse stakeholders to share knowledge. ACES was established in 2020 with the joint effort of the UK and Rwandan governments, the United Nations Environment Programme, and academic and policy partners in the two countries (U4E 2022)[4] (more about ACES is provided in Box 5.2). The success of this or any such initiative depends on the ACES' or any recognized central coordinating body's ability to gather expertise and experience; empower implementation across multiple stakeholders; and identify lessons from diverse programs and initiatives to present best practices and guidance for a range of circumstances and goals.

Much needs to be done through the above intersectoral policy efforts to promote cooling; strengthen and scale up support for the development of off-grid household, rural agricultural, and health care cold chain markets; and improve these markets' operations. This will help unleash opportunities from mainstreaming appropriate low-carbon cooling facilities and appliances for the productive use of renewable energy, including off-grid cooling appliances, by different micro, small, and medium enterprise value chains.

BOX 5.2

AFRICA CENTRE OF EXCELLENCE FOR SUSTAINABLE COOLING AND COLD-CHAIN

The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES), which aligns with many governments' climate commitments and the Kigali Amendment, is envisioned to facilitate a Pan-African collaboration on the development and adoption of sustainable cooling and cold chains. To that end, ACES is intended to function as a center of excellence that will lead applied research, the dissemination of knowledge/ideas, and the advancement of cross-stakeholder collaboration in a cross-cutting sectoral setting. ACES has four focus areas, which are mentioned below.

ACES is conceptualized as a hub-and-spoke model. Its Rwanda-based headquarters will act as the hub that creates solutions and passes them on to the market through the spoke centers spread across the African continent. The main nodes of intervention are (1) technology, (2) business, (3) research, and (4) knowledge. Although ACES is still in its early stages, it has already conducted a cooling needs assessment study and has also established its first spoke in Kenya. Emulating this model, another center of excellence was established in India in early 2022 (India Centre of Excellence in Sustainable Cooling and Cold-Chain/ACES-Asia).

Source: U4E 2022.

Support policies could consider simplifying business registration, licensing, and legal and technical requirements to operate. It may also be necessary to improve road networks to allow easy delivery of perishable products—food and medicines. Road network improvement is crucial since poor roads or absence of roads could restrict vehicles from reaching specific areas and compromise refrigeration-equipped trucks/vehicles, causing leakage of high-global-warming-potential refrigerants and generating higher operation costs. For physical infrastructure, policies could include accelerated railroad expansion and the configuration of specifications for cooling trucks, vans, and cold storage boxes, among others.

Creating an Enabling Environment for the Provision of Access to Cooling Services

Regulations, Standards, and Quality Assurance

Cooling and cold storage equipment represent a significant investment for all stakeholders, including off-grid households, farmers, and entrepreneurs, as well as larger organizations and governments. Substandard, inefficient, and inappropriate equipment could be financially devastating (especially the more expensive refrigeration appliances and facilities) for consumers and producers and could undermine the urgent acceleration of cold chain access. The long-term transformation of the off-grid cooling sector will require policy support to address these issues. Policies should include, as a key parameter, the reduction of hydrofluorocarbon refrigerants (where used), to aid in greenhouse gas emission mitigation. NCAPs and other guiding policy frameworks typically address equipment such as fans, refrigerators, freezers, and air conditioners, but have not included walk-in cold rooms. MEPSs, or at least performance benchmarks, for these appliances are seen as crucial to limit growth in energy demand and potential emissions.

Testing, standards development, and a range of ancillary "quality assurance (QA)" services, including warranties and compliance monitoring, have been crucial in catalyzing the growth of the global off-grid solar market to date, as well as the growth of most appliance markets the world over. The World Bank Group–funded Lighting Global family of programs coordinated and supported the development of QA frameworks for off-grid solar lamps and solar energy kits. Over 10 years, this grew into its own third-party quality verification program known as VeraSol (managed by the nonprofit Collaborative Labeling and Appliance Standards Program [CLASP]), which is now the *de facto* standard adopted by global governments and development partners as an essential eligibility criterion to qualify for different incentives such as tax breaks and access to concessional finance programs (typically providing working capital loans to local distributors and results-based financing to accelerate product sales). The QA-related policies that the World Bank Group implemented in its off-grid solar promotion programs through national projects, Lighting Africa and Lighting Global, have consistently included support only for products meeting the agreed quality standards, provision of dealer-backed warranties, and ensuring compliance through verification.

This successful approach can be expected to also underpin the future success of the market for off-grid-appropriate cooling appliances (see Appendix C for a suggested template). The Efficient and Clean Cooling Program, led by the Energy Sector Management Assistance Program (ESMAP), has just begun funding a two-year initiative to assist VeraSol expand its testing methodologies and quality standards for stand-alone solar powered refrigerators and freezers as well as develop a framework for the appropriate use of standards for walk-in cold rooms alongside providing technical assistance to African governments to adopt these standards as eligibility criteria to determine which appliances are supported in their national off-grid energy and cooling access programs. In general, QA for off-grid power systems and appliances is seeing increasing demand, including expansion to include more product categories. Many governments and development partners have a strong desire to expand beyond solar energy kits to cover component-based systems, systems for public institutions, solar-powered appliances, and productive use equipment.

Programs by governments, development partners, development finance institutions, and multilateral development banks to promote and support off-grid cooling appliances need to support access to equipment or facilities only when they meet quality benchmarks or quality standards that have been established. Ultimately, a Quality Assurance framework is essential that includes not only agreed quality standards, but supplier-backed warranties for purchasers of products and verification of compliance.

This nascent stage in the development of climate-friendly off grid-/weak-grid cooling solutions presents an opportune moment to formulate complementary policies/programs that can further boost access to efficient and superior clean energy systems and cooling equipment. A good case for this can be seen in India's Super-Efficient Equipment Programme, which seeks to make ceiling fans 50 percent more efficient by providing time-bound financial incentives for fan manufacturers to produce superefficient appliances to be sold at reduced prices (IEA 2021b).

CONCESSIONAL FINANCING FOR COOLING EQUIPMENT SUPPLIERS AND END-USER SUBSIDIES

Experience with programs to increase access to other technologies such as solar home systems (SHSs) and related appliances has shown the importance of concessional financing to equipment suppliers in early years to attract them to a new technology, help them to establish new product lines and to provide financing to their customers to increase affordability. End-user subsidies for new technologies have also been shown to help to increase early adoption and to reach vulnerable populations. These elements have been included in most of the successful SHS promotional activities carried out at national level by the World Bank and in worldwide efforts such as the Lighting Africa/Lighting Global Programs (see Box 4.1).

One of the most successful World Bank–assisted national programs was the Bangladesh Solar Home System Program that installed 4.1 million SHSs from 2003 to 2018, building on the government's commitment to universal access and earlier SHS activities. Concessional loans to participating suppliers help them build the capacity to sell and service qualified systems and to make financing available to their customers.[5] The concessional financing had longer loan tenors and grace periods and lower interest rates at the beginning and became less concessional over time.[6] After 2008, terms varied with the size of the loans, with smaller loans receiving more concessional terms. Two types of subsidies were used in the program, financed by grants to the government: (1) small grants to SHS suppliers to establish the retail service infrastructure and (2) up-front end user subsidies to buy down the capital cost of the equipment. Per unit subsidies declined over time from 18 percent of the system cost in 2018 to 4–8 percent from 2006 onward; from 2012 the only grant offered was US$20/SHS of less than 30Wp (Cabraal et al. 2021).

Up-front subsidies will be especially important to make cooling appliances affordable to rural low-income people living in off-grid areas with limited access to infrastructure and resources. Such subsidies for the purchase of equipment/facilities by households, farmers and microenterprises can help increase rates of adoption of the technology. They can also make small appliances more affordable to the most vulnerable, since people living at or near the poverty line may not be able to use PAYG or access credit.

Another example of subsidies to promote an emerging technology is the African Development Bank's grant to South Sudan to help install 1,170 solar pumps—the grant covering 75 percent of the cost to farmers. The grant is also being used to establish workshops to maintain the pumps and a pump testing laboratory to provide certification and training. The scheme is intended to enhance agricultural communities, increase food security and reduce CO_2 emissions by replacing diesel pumps (AfDB 2019).

PUBLIC AWARENESS AND BEHAVIORAL CHANGE

Information is crucial for increased consumer awareness and to ensure policy success. Support for promoting awareness and behavioral change can contribute to ensuring access to sustainable cooling in rural areas, where awareness is typically low.

Awareness campaigns can first help encourage a transition to high-efficiency off-grid cooling equipment and its proper management. An example of this can be found in Rwanda, whose national cooling strategy included an awareness campaign under the Rwanda R-COOL initiative. The campaign promoted financial and energy savings due to high-efficiency (on-grid) refrigerators and air conditioners, showing consumers why they should switch to those appliances. Awareness efforts have also proven to be crucial in the uptake of community cooling resources and the implementation of local heat action plans where adaptive capacity to heat is low (Widerynski et al. 2017). Women and children should be considered a vulnerable group and a priority for public awareness programs. For example, lessons can be drawn from the Ahmedabad Heat Action Plan, which included specific measures to educate young girls, mothers, and the elderly.

Especially in agriculture, lack of information tends to coincide with the absence of cold chain systems. For instance, an internal assessment for the World Bank–funded national livestock and dairy development program in Bangladesh found that neither consumers nor farmers (or the middlemen) were aware of the need to process milk expeditiously for safe consumption. As for the meat industry, there appeared to be a lack of cooling facilities as well as a misguided perception about meat's freshness (unfrozen meat in live markets is preferred to frozen meat). Awareness campaigns on safe food consumption can modify consumer behavior and incentivize dairy farmers and meat producers to adopt refrigeration in the production process (see Box 5.3).

BOX 5.3

AWARENESS CREATION FOR ENERGY-EFFICIENT AGRICULTURAL COLD STORAGE IN RWANDA

Limited development of agriculture value chains in Rwanda has led to a lack of appropriate storage and processing infrastructure, including limited access to cold storage. Small- and medium-sized farmers mostly rely on basic off-the-ground storage facilities or cooperative-owned facilities, which lack temperature control. There are barriers to the establishment of closed cold chains for perishable commodities such as dairy and horticulture produce. This results in persistent high postharvest losses. Although cold rooms and solar-powered storage facilities are present, they are under limited operation and utilization.

The World Bank's Energy Sector Management Assistance Program (ESMAP) funded two successive rounds of technical assistance (TA) in Rwanda, with an aim to improve the country's cold chain infrastructure. The first TA diagnosed the current situation of cold chain utilization in the horticulture value chain. It assessed barriers to the adoption of existing cold storage technologies, conducted a stocktaking of international experiences, and recommended a roadmap for deploying energy-efficient cold chains. The second TA followed up on the recommendations of the first TA and sought greater adoption of cold storage facilities through an information campaign and implementation support. It targeted small- and medium-sized farmers, agribusinesses, and stakeholders in the value chain. Recommendations from the second TA included addressing technology gaps, establishing private-sector-driven management, developing standard operating procedures for postharvest handling, and adapting regulations to align with priorities.

Cold Storage Room, Rwanda. *Source:* Frank Kanyesigye, PIU, Rwanda Agriculture and Animal Resources Development Board.

(*continues*)

BOX 5.3 (*Continued*)

The TA supported interventions to raise awareness of the benefits of climate-friendly and energy-efficient cold chain facilities, and it proposed operation and management models for the targeted areas. The objective was to make the cold chain infrastructure in Rwanda more efficient and effective, in turn supporting the agriculture sector's growth and addressing the increasing demands of the domestic and potential regional and international markets (see the full case study in Appendix A).

Source: World Bank 2023.

CAPACITY BUILDING AND TRAINING

Fundamental education, skill development, and project services are key to behavioral change. They help realize energy savings and aid in long-term cooling-related decision making. Successfully implementing an NCAP or other cooling-access-related policy strategy requires significant efforts to train public and private stakeholders and build their capacity. The India Cooling Action Plan, for example, included a specific target of training 100,000 service sector technicians by 2023 to maintain the efficacy of sustainable cooling equipment (Ozone Cell 2019). Vocational and professional schools need to develop, expand, and implement the training needed to develop engineers and technicians, who constitute the skilled work force required to ensure proper repair and maintenance of cooling equipment. Special efforts will be needed to ensure such technicians are available in rural areas, especially off-grid rural areas, and that they have adequate skills to repair not only the equipment, but the equipment providing stand-alone power, if necessary.

Education is also capacity building. It can range from basic education—primary school—to university education and support to improved decision-making for a larger share of the population or increased innovation for a smaller group. Efforts to build awareness, knowledge and skills of girls and female professionals are crucial to increase participation of women in the sustainable cooling workforce, supporting income creation and equal representation in labor decision-making in the sector.

Capacity can also be built through project services, often provided by engineers, designers, architects, or contractors, who are fundamental for expanding access to sustainable cooling. Finally, long-term institutional capacity building is critical in countries with significant populations at risk due to heat stress and a lack of access to cooling. This can be achieved, for example, through finance for long-term training and capacity building, training programs in universities and technical institutes dedicated to sustainable cooling, and new officials dedicated to sustainable cooling in environment or energy ministries and local governments.

DATA, TRACKING, AND REPORTING

Adequate policy information and data are needed to support international cooperation and action. Progress-tracking efforts such as the Regulatory Indicators for Sustainable Energy have helped fill a critical gap in policymakers' and development financiers' understanding of the existence and rigor of policies for sustainable energy. The Chilling Prospects 2022 report (SEforALL 2022a) included a general review of policy progress for access to sustainable cooling among the "Critical Nine" high-impact countries (Bangladesh, Brazil, China, India, Indonesia, Mozambique, Nigeria, Pakistan, and Sudan). The exercise included mapping policies enhancing cooling access, strengthening energy efficiency, and reflecting cooling in adaptation and mitigation plans. It highlighted a consistent information gap on energy efficiency standards among key stakeholders and policymakers and a lack of agreement on proven effective incentives for off-grid cooling devices. It indicated a need for a more comprehensive approach encompassing a wider spectrum of countries and policies promoting rural cooling access. Such an effort would allow policymakers to benchmark their policies and send a strong signal for investors to move toward efficient off-grid appliances and advance climate and development targets.

Data limitations at the country and local level have been a key barrier to policy and planning processes and investment. The limitations are partly due to the topic's nascency, but also due to the broad variety of data necessary to measure need for and achievement of improved cooling access across multiple sectors. Market attributes in rural settings (e.g., willingness to pay and the cost of after-sales service and maintenance for cooling equipment) are not well known, despite the increasing efficacy, efficiency, and affordability of off-grid cooling appliances. Further, there is also a lack of data on public and private investment on equipment stock, as well as on sales and inventories. This can hinder the establishment of a baseline for action and plans for action. Meanwhile, where investment data exist, they are narrow in scope, typically lacking project- or transaction-level information. This is in addition to the lack of data on commercial performance and financial viability or return on investment, as well as investments other than those in equipment stock, for example, passive cooling (SEforALL 2021c).

Specific challenges include a lack of data supporting the socioeconomic benefits of many types of interventions, including those related to gender. A lack of gender-disaggregated data prevents an understanding of gender-differentiated vulnerabilities (SEforALL 2021b). Data is the first step in developing gender-inclusive sustainable cooling solutions and initiatives, but collection and tracking of sex-disaggregated remains limited. Key data that need urgent gathering and updating include information on the gender dimensions of vulnerability and poverty in rural areas, on the purchase and use of rural cooling technologies and services, on the heat-related health risk, and on participation in the formal and informal workforce. Sustainable Energy for All (SEforALL 2021b) provides recommendations on specific, measurable, achievable, relevant, and timebound indicators; these recommendations should be further adapted to rural contexts.

New data are being collected, and supporting data capture and analysis tools are increasingly being developed to meet the tracking, reporting, and investment needs, including in rural areas. This includes SEforALL's efforts to model the impact of temperature, cooling degree days, income levels, and cooling appliance ownership rates in India and Mexico, among other countries. Analysis of this type can support localized plans, help improve resource allocation in constrained settings, and inform national cooling plans, notably in countries with significant income disparities (SEforALL 2021d).

Endnotes

1. Refer to the Ministry of Water, Irrigation, and Energy (2019) for an example of the detailed information available in an integrated electrification plan, including household survey information.
2. Refer to the work of SEforALL and CLASP (2021) on cooling adaptation in the MTF.
3. For instance, India's Ministry of New and Renewable Energy launched the scheme "Scale Up of Access to Clean Energy for Rural Productive Use" to endorse the implementation of new renewable energy technologies (e.g., solar refrigerators, solar dryers, and solar aerators) for rural productive use/livelihoods in underserved states. The overall off-grid solar refrigerator demand is anticipated to grow in the near future, with improved living standards of rural consumers.
4. Centre for Sustainable Cooling; UK academic partners include the University of Birmingham, London South Bank University, Centre for Sustainable Road Freight, and Cranfield University.
5. The average financing terms provided by SHS suppliers to end users in the Bangladesh program were 15 percent down payment and a three-year term, with a 14 percent average flat interest rate.
6. Between 2003 and 2008, financing had 10-year terms, grace periods of 2 years, and interest rates of 6 percent. By 2016–17, loan terms were 5–7 years, grace periods were 0.5–1 year, and interest rates were 6–7 percent.

SIX

CONCLUSIONS AND RECOMMENDATIONS—A CALL TO ACTION

The ongoing rise in global average temperatures and prolonged periods of heat stress due to climate impacts highlight the urgency of action for improved cooling access in rural off-grid areas, especially for human safety and comfort, agriculture and food, and health care. Given the strong link between cooling and electricity, the impoverished and vulnerable—who suffer the least access to electricity—are exposed to greater impacts of lack of cooling access exacerbated by temperature increases due to global warming. Access to cooling is an enabler in reaching multiple SDGs for example by increasing food security, climate resilience and incomes; therefore, cooling must be considered an essential service within the Energy Access Multi-Tier Framework.

Access to electricity can help meet critical cooling needs by powering fans that provide families and workers relief from heat stress in heat waves, or refrigerators that preserve food quality and help store critical vaccines safely, or cold storage rooms that extend the life of produce and increase incomes of rural producers. At the same time, access to affordable cooling and refrigeration, for both commercial and household use, is among the top services in demand in developing rural areas and can boost rural electricity demand. Efficient cooling devices can help off-grid electricity access markets grow by providing a service that is highly desirable to off-grid consumers (access to fans, refrigerators, etc.) and off-grid solar system providers (by helping to increase and aggregate solar system demand). Increasing access to electricity and cooling simultaneously creates synergistic development impacts.

Despite the preliminary nature of this report, it is clear that an order of magnitude increase in focus and effort is needed on the nexus of accelerating access to sustainable cooling and clean energy in rural off-grid areas, akin to the concentrated effort to advance urban cooling in recent years. Public funding is needed for programs, projects, and activities to make sustainable cooling technologies at different stages of market readiness more accessible through pilots, demonstrations, and scale-up efforts. Monitoring, documentation, and sharing of early experiences will be essential to build knowledge and enable successful larger-scale efforts.

While this report represents only the beginning of the discussion on access to sustainable and efficient off-grid rural cooling and the nexus with access to electricity, it suggests a number of early recommendations to expedite the uptake of cooling in off-grid areas with respect to policy measures; innovation in technology and promotion of business models; financing approaches; information, awareness and capacity building; and, key steps to increasing access. A concerted effort by stakeholders across sectors is needed in order to deliver truly sustainable and commercially viable cooling solutions that are affordable for rural off-grid consumers.

Policy Measures

Integrate Rural Cooling Access with Energy Access, Economic Development, and Climate Change Policies and Plans

Integrating programs and activities to meet rural cooling needs into national electrification strategies or integrated energy plans and sectoral and economic development strategies is a powerful tool to increase off-grid cooling access. When cooling interventions are well integrated into related activities under sectoral policies or plans, the potential for impact and sustainability can be increased. Integrating programs for off-grid electrification and cooling facilities/cold chains to extend the life of produce and agricultural/dairy/fishery products into agricultural policies and plans and programs for off-grid electrification and space cooling/vaccine refrigeration for rural health centers into health care policies and plans could be especially significant.

Cooling access can also be promoted through climate action policy frameworks, including Nationally Determined Contributions, national adaptation plans, and national energy efficiency strategies. National cooling action plans (NCAPs) are also useful tools, which supports the implementation of the Kigali Amendment to the Montreal Protocol with holistic strategies to address hydrofluorocarbon phasedown, energy efficiency, climate change, and the Sustainable Development Goals. To serve rural populations effectively, however, NCAPs must strive to make sustainable and affordable cooling solutions more accessible.

Including gender considerations in developing and implementing policies and action plans will support gender equality in achieving access to sustainable cooling. This includes integrating gender-based analyses, sex-disaggregated indicators, and participatory mechanisms to inform the design of policies and tracking of outcomes.

Adopt Regulations, Standards, and Quality Assurance for Off-Grid Cooling Appliances

Experience from efficient off-grid lighting programs using solar technologies has demonstrated the value of linking incentives to a quality-driven approach. Similar regulations, standards, and quality assurance are needed to effectively channel incentives and financing to increase access to high-quality, high-efficiency cooling equipment, which minimizes hydrofluorocarbon refrigerants. Quality assurance (including product standards, supplier-backed warranties, and compliance monitoring) also helps guarantee product performance and safeguard end users. Work is already underway to develop off-grid (solar) refrigerator standards (IEC 2022); this needs to be extended across the range of off-grid cooling equipment covered in this report.

The verifiable implementation of the refrigerant requirements set out in the Kigali Amendment to the Montreal Protocol creates a regulatory push that can extend to energy efficiency improvement.

Implement Institutional Coordination for Increasing Access to Rural Off-Grid Cooling Services

Since promotion of rural cooling cuts across sectors, it requires communities of practice on sustainable cooling at the country and local level with representation across ministries and agencies, civil society and the private sector. Considering the various sectors with needs for cooling in off-grid rural areas, ensuring that activities are coordinated and not conflicting remains a priority. Some of the responsibilities could include identifying data gaps (SEforALL and CLASP 2021); coordinating with experts and civil servants to draft, update, and integrate NCAPs or other implementation strategies; and mobilizing funding for implementation, along with research and development. Regionally, the Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES) is a promising initiative that could be replicated or expanded, if evidence demonstrates that it has been effective in sharing and applying best practices and lessons learned.

Innovation in Technology and Promotion of Business Models

Invest in Pro-rural, Pro-poor Technology Innovation for Off-Grid Rural Cooling

Technology for off-grid rural applications must be robust, of superior quality, highly efficient, and, above all, affordable. Globally, only a handful of specialized companies, institutions, and development partners have been actively designing and implementing sustainable off-grid cooling solutions. Off-grid passive cooling solutions have seen little widespread promotion in rural areas. Off-grid fans are the most widely adopted cooling technology, integrated with solar home systems. Cold storage for agricultural products, dairy and fisheries is the most developed of agricultural cooling technologies but markets are nascent. In health care, large-scale purchases by GAVI, UNICEF and the WHO have driven strong market development, especially because of the need for COVID-19 vaccine refrigeration.

To deliver sustainable cooling for all, there must be a steep increase in public finance for innovation to create technology solutions that are available and affordable for off-grid, low-income rural consumers. Also crucial are efforts to ensure that men and women benefit equally from inclusive solutions and have equal opportunities to shape innovations. Data compiled as part of the Cool Coalition Global Stocktake suggest that over the past six years, technology innovation has received only about 16 percent of the public/philanthropic funds to promote sustainable cooling. Moreover, much of this financing is directed toward higher-income consumer segments, with access to grid-connected energy.

Promote Business Models for Affordable Off-Grid Cooling Solutions and Durable Markets

The private sector has demonstrated innovation and initiative in developing transaction models for off-grid electrification to address key challenges on affordability/high up-front costs and adequate consumer protection (quality control, warranties, maintenance, after-sales service, etc.). The affordability issue is being partially addressed by business models such as pay-as-you-go (PAYG) and cooling as a service (CaaS), as long as they are combined with adequate access to finance for all the supply chain actors. These models reduce up-front costs by spreading payment over a longer term, but create financing challenges for suppliers that must carry costs longer. Bulk procurement by health care institutions reduces equipment costs through economies of scale, although adequate maintenance is not always guaranteed. Governments and program partners should learn from these experiences; they must adapt the financing and delivery models for off-grid electricity infrastructure for cooling infrastructure and build on the limited experience to date with cooling infrastructure.

Public finance is needed to pilot, demonstrate, and scale up innovative business models that enable access to sustainable cooling in off-grid areas now and help develop durable markets in the long term. Off-grid fans are sold by the private sector alone or bundled with solar systems, on a cash or PAYG basis. Off-grid refrigerators and freezers are sold on a cash or PAYG basis on a much smaller scale, for use in homes, microenterprises, and by farmers. Walk-in cool rooms to increase agricultural productivity have been used at demonstration scale usually with Cooling as Service (CaaS) models where groups of farmers or operators supply cooling services for a fee. Bulk procurement has been used in the health care sector to lower costs but needs to ensure adequate operation and maintenance in contracts. Finally, building codes or voluntary standards could be revised (or created) to include cool roofs as requirements for publicly funded buildings and to act as gatekeepers for financial incentives to buildings in rural areas. All of these applications of business models and more need to be scaled up through programs, projects or pilot activities as described in the next subsection.

Based on the experiences in the off-grid lighting sector, public and philanthropic investment should aim to support the scale-up of market-ready and near-market-ready applications using business models that make sustainable solutions affordable for low-income rural consumers. Investments must be coupled with robust capacity building and business analytics for suppliers. Public finance combined with private sector implementation, considering cooling as critical infrastructure, will be crucial in the and must be designed for an eventual transition to more commercial private sector models.

Finance for Sustainable Off-Grid Rural Cooling

Use Public and Blended Finance Mechanisms

Blended finance utilizes small sums to catalyze substantial additional finance from development finance institutions, which can in turn leverage even greater funding from local banks and leasing companies. Although blended finance approaches may be new in the cooling space, they have been used extensively in the climate space. There is a large body of experience on which to base new approaches in cooling.

Blended finance (Convergence n.d.) is critical for creating an enabling environment for the cooling sector to develop at a desired scale. Development finance institutions, while public, often invest with a commercial mandate and may deploy concessional funding on behalf of development agencies, provide credit enhancement or other risk participation, or play an important role in arranging finance.

Blended finance may be accessed through bilateral arrangements with donors or by accessing climate finance facilities. Expanding the use of blended finance will require additional funding from donors, including philanthropic foundations. Depending on the circumstances, this may involve renegotiating agreements to enable fund utilization for investment purposes as well as to support additional relevant technical-assistance-type activities.

Leverage Climate Finance Facilities for Rural Cooling Needs

Sustainable cooling addresses both climate change adaptation and mitigation and can thus access both channels of climate finance. New programs for off-grid cooling must be designed considering both windows for adaptation and mitigation. Project sponsors should be able to delineate their projects' adaptation and mitigation elements to be able to tap into single-purpose funds.

Climate finance to support mitigation and adaptation in rural settings can also seek to leverage the electricity access–cooling access nexus. The Climate Investment Fund's Scaling Up Renewable Energy Program in Low Income Countries, for example, uses climate finance to scale up renewable energy for electricity access. Public energy financing programs to electrify underserved communities could include rural cooling solutions, after considering factors such as the institutional capacity of the government agency, potential partners, insights from market intelligence, the market development stage, consumers' profile, and probable risks in all stages of implementation, including market risks (domestic and international).

Information, Awareness, and Capacity Building

Increase Data Collection, Tracking, and Reporting

New data and supporting tools developed by Sustainable Energy for All (SEforALL), the Cool Coalition (led by the United Nations Environment Programme), and others are increasingly addressing tracking, reporting, and investment needs, including in rural areas. Improved analytics and market data can support local plans, improve resource allocation in constrained settings, and inform electrification strategies and national cooling plans, notably in countries with significant income disparities (SEforALL 2021d). Additional, localized data on costs and economic analysis is crucial to supporting investment by determining market size, ability to pay, and locally suitable business models.

Data collection to support strategic and project-level decision-making needs to continue, expand, and accelerate but must follow an agreed-upon common format. This will allow different bodies to coordinate and execute their efforts in a manner that allows combining and analyzing data based on an agreed set of progress-tracking metrics. Focus areas for data collection include potential cooling needs for and impacts on children's ability to study; productivity gaps for different occupations; vulnerable people's health and well-being; food loss and agricultural productivity; gender-differentiated cooling needs and impacts; and animal welfare. Data on product performance could be collected via remote monitoring software and hardware installed in cooling appliances and facilities. These software and hardware can alert suppliers to maintenance needs, and their installation could be incorporated into policies as an eligibility criterion for equipment procurement by public or donor programs.

Increase Public Awareness and Behavioral Change

The public is increasingly aware of the impacts of heat on food safety and human well-being, and the need for vaccine cold storage. But greater awareness is needed on what they themselves and others can do to alleviate problems. In the agriculture sector in particular, lack of information tends to coincide with the absence of local availability of cold chain systems or a lack of their utilization, where available. Awareness campaigns on safe food consumption can nudge consumer behavior and incentivize dairy farmers and meat producers to adopt refrigeration in the production process.

Awareness campaigns through the press, radio, civil society, and local governments are needed to encourage a transition toward more energy-efficient cooling equipment and proper management in all sectors. Awareness efforts have also proven to be crucial in the uptake of community cooling resources and the implementation of local heat-related action plans where adaptive capacity to heat is low (Widerynski et al. 2017). These efforts provide an opportunity to engage at-risk groups such as women and children and reduce their vulnerability.

Build Long-Term Institutional Capacity for Off-Grid Sustainable Rural Cooling

Increased access to cooling requires capacity building and training public and private stakeholders. There is a critical need for national and local government institutions and ministries (e.g., the ministries of rural development, agriculture, health, energy, and environment) to build knowledge, capacity, and skills at all levels, including among their officials, to address rural off-grid cooling needs and seize opportunities. This is especially important in countries with significant populations at risk due to heat stress and a lack of access to cooling. This can be achieved, for example, through finance for long-term training and capacity building, expansion of cooling-related technical programs in universities and technical institutes, and funding new staff positions dedicated to sustainable cooling in ministries and local governments.

Build a Skilled Technical Labor Force to Support Off-Grid Sustainable Cooling

This includes skill training and capacity building for the "cool jobs" that need to be created, and to ensure equal participation of women and men in the sustainable cooling workforce. Support needs to be provided to create the technical work force required to install, operate and service off-grid cooling equipment at local level and to build the technical workforce capable of designing and installing larger off-grid cooling facilities like agricultural walk-in cold rooms at national level. This must incorporate efforts to build skills and competence of women and girls. Technical capacity will also be needed to adequately and safely manipulate refrigerants to ensure safety and minimize leakage.

The nationwide use of solar photovoltaic systems for off-grid electrification translates to the important need of upskilling a cohort of technicians including women and men in rural off-grid areas who are trained in maintaining and repairing, for example, clean refrigerators and are familiar with solar technology. Facilities/technologies allowing remote and early equipment diagnosis (preventative maintenance) in off-grid areas may also be useful. Vocational institutes or even community-based organizations could provide gender-inclusive training in handling relatively low-tech passive cooling solutions.

Key Steps to Expand Access to Sustainable Off-Grid Rural Cooling

More programs, projects, and pilots to expand rural off-grid access to sustainable cooling are needed. Planning and implementing them within, or in close coordination with, sectoral programs will increase the probability of their success and sustainability. This will also increase the probability of successful activities being replicated and expanded. As in the case of rural electrification in off grid areas, these programs will need to use a market approach as much as possible whenever there is sufficient capacity to pay from users, and combine this with an approach of public private collaboration when addressing cooling need for the last mile customers, when public subsidies would be needed to harness the advantages of private providers efficiency and scale, while making the cooling appliances affordable for the poorest customers. These programs should incorporate to the extent possible elements like those in the Lighting Global Program (see Box 4.1) including awareness creation, capacity building of suppliers, concessional financing to suppliers, quality assurance (standards, supplier-backed warranties, compliance monitoring) and end-user subsidies. Different off-grid cooling technologies and national markets at different developmental stages need different blends of these elements. There is no 'one size fits all' approach.

Expanding Access to Space Cooling

Installing a cool roof and planting shade trees require little capital investment, as does simply whitewashing walls. Ensuring that houses and buildings are built with adequate ventilation and benefitting from traditional architectural practices is key to build resilient and comfortable structures that minimize the need for active cooling. Further, off-grid fans provide significant benefits and can be supplied commercially alongside stand-alone solar systems in some off-grid areas, but are only being purchased by a small share of off-grid rural households worldwide. Evaporative air chillers are emerging in a few suitable geographies, while air conditioners and similar appliances remain unaffordable and power intensive.

Programs, projects and pilots to promote sustainable off-grid space cooling need to be carried out as part of energy access or rural development sectoral programs. These could focus first on low-cost passive solutions and then on off-grid fans using cash and PAYG models, ideally in association with national distributed renewable electrification programs where these exist. One focus should be to increase the number and size of suppliers so that solutions can be delivered at scale. The bulk of support needs to focus on financial instruments, for example, incentivizing early-stage market growth through results-based financing to reduce costs, risk-sharing and patient capital facilities to encourage lending to operators, distributors, and end-users by local banks and leasing companies to support service providers or consumers. End user subsidies may also be needed to reach the most vulnerable who may not have bank accounts and cannot use PAYG. Studies of rural space cooling needs must be scaled up to better quantify the benefits from options for intervention and determine people's ability to pay.

Expanding Access to Agricultural Cold Chains

Supporting cold chains that boost farm income and enable nutrition continues to be a challenging endeavor that is best done through programs, projects and pilots that are fully integrated into agricultural sector programs, complementing other activities that target increasing productivity and incomes of farmers and fishermen. There are two promising areas that could make a major contribution to reducing agricultural waste and increasing productivity and incomes of farmers in off-grid rural areas. One is promotion of off-grid refrigerators and freezers for micro-enterprise, agricultural, dairy, fisheries and livestock value chains. These are market ready but require scale-up and cost reduction, through activities to demonstrate effectiveness and increase use, incorporating appropriate levels of subsidy given the relatively high cost of the equipment and taking care to ensure effective after-sales service and maintenance. The other is improving access to off-grid agricultural walk-in cold storage rooms and similar emerging agricultural refrigeration through demonstration and scale-up activities for both technologies and business models to aggregate farmers' needs affordably.

In this regard, the approach must consider an equitable financial return to smallholder farmers, farmers' cooperatives, and/or CaaS providers on their investments in appropriate cooling technology (SEforALL 2020c). There exists an increasingly large body of work on agri-finance for smallholders to improve their access to inputs, including tools and shared infrastructure such as tractors. Pay-as-you-store or use models (for farmers) and warehouse finance models (for operators) may also be made feasible by aggregating the demand from smallholder farmers. Targeted efforts to address gender-based barriers are often necessary to support equal participation of men and women and to enhance rural women's access to resources, markets and productive assets. This will in turn improve their income and heat resilience and make a positive contribution to food security.

Expanding Access to Sustainable Cooling in Healthcare

Scaling up efforts to provide sustainable cooling for health care facilities in developing countries and more specifically in remote off grid rural areas is a critical link to expand provision of basic health services to these population. As demonstrated during the COVID 19 pandemic, having an efficient cold chain to refrigerate and transport COVID vaccine was required for the success of the vaccination campaigns. Cooling needs however are broader for providing adequate basic health services. Temperature control (cooling) is also necessary for the storage of medications and blood and for the conservation of samples in laboratories, cooling plays an important role in various medical equipment, and finally cooling of medical facilities contributes to improving living and working conditions for patients and medical workers. These cooling needs must be fully integrated into health care programs that target improving services in rural areas. Bulk purchase of off-grid electrification systems and/or solar direct drive vaccine refrigerators has already taken place in many countries as part of health care programs, especially driven by COVID-19. However, in poorer countries, where markets and delivery mechanisms for new technologies rarely exist, governments and health care partners must use their limited resources to purchase and maintain cold chain equipment (GAVI 2018) and much remains to be done to provide off-grid electrification for cooling and off-grid vaccine storage.

Bulk procurement of items such as cool roofs for clinics, blinds fans and air conditioning equipment can expedite the adoption of sustainable cooling in the health sector by reducing overall installation costs, as long as they ensure repair and maintenance support. For energy services within clinics, energy service company models or public-private partnership approaches may be appropriate alternatives to bulk procurement with contracts that include service and maintenance. Programs to support electrification and expansion of sustainable cooling, which focus on developing a sector-wide approach rather than implementing for a few health centers at the time could benefit not only from larger scale economies when purchasing equipment or signing contracts with private providers; they could also be better equipped to address the issue of securing sustainability of the results by supporting the establishment of standard maintenance programs, inclusion of budget lines in ministry of health to ensure funding of maintenance and training by the electrification and cooling providers of technicians from the maintenance crew responsible for other equipment in local facilities, who could take over routine maintenance for both electricity and cooling equipment after their training.

To enable the different business models for cooling in the health sector to materialize, there may be a need to educate financial institutions in lending to entities of this type as well as financial instruments such as guarantees. There may also be opportunities to buy down capital costs through accessing climate funds.

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Glossary of Terms

Urban heat island effect (UHIE)	Heat islands are urbanized areas that experience higher temperatures than outlying areas. Structures such as buildings, roads, and other infrastructure absorb and reemit the sun's heat more than natural landscapes such as forests and water bodies. Urban areas, which have a high concentration of these structures and limited greenery, become "islands" of higher temperatures relative to outlying areas.
Food loss, food waste, and food wastage	Food loss, food waste, and food wastage are terms related to the food supply chain. Food loss is the unintended reduction in food available for human consumption, resulting from inefficiencies in supply chains: poor infrastructure and logistics or lack of technology, insufficient skills or poor management capacity. Food waste refers to discarding or alternative (non-food) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer level. Food wastage encompasses both food loss and food waste.
Global warming potential (GWP)	The term was developed to allow comparing the global warming impacts of different gases. Specifically, it is a measure of the amount of energy consumed in the emission of 1 ton of a gas over a given period relative to the emission of 1 ton of carbon dioxide.
Solar home systems (SHS)	These are stand-alone photovoltaic systems that enable supplying power for lighting and appliances cost-effectively to remote off-grid households. In off-grid rural areas, SHS can enable a household to meet its energy demand for basic electricity. SHS provide power to hundreds of thousands of households in remote areas where grid electrification is not feasible. SHSs typically operate at a rated voltage of 12 volts. They run on direct current (DC) and power low-power DC appliances, such as lights, radios, and small TVs, for about three to five hours a day.
Pay-as-you-go (PAYG)	This is a business model that eliminates the up-front cost barrier for SHSs by allowing end users to pay in affordable amounts over time. The cost reduction is achieved by additional electronics, which activate or deactivate SHSs on request. This helps in achieving a top-up payment structure similar to mobile phones.

Phase-change materials (PCMs)	These are substances that absorb or release large amounts of so-called "latent" heat when they undergo a change in their physical state, that is, from solid to liquid, and vice versa.
National cooling action plans (NCAPs)	They help countries identify pathways to integrate comprehensive action for mitigating energy-related emissions from cooling. These actions are aligned with plans related to emissions from refrigerant transition.
Energy service company (ESCO)	This is a company that provides a broad range of energy solutions, including design and implementation of energy savings projects, retrofitting, energy conservation, energy infrastructure outsourcing, power generation, energy supply, and risk management. A newer breed of ESCOs includes innovative financing methods such as off–balance sheet mechanisms and provide a range of applicable equipment configured to reduce a building's energy cost. The energy cost savings are often used to pay back a project's capital investment over 5–20 years or are reinvested into the building to allow capital upgrades that may otherwise be unfeasible. Failure of a project to generate investment returns often results in the ESCO paying the difference.

APPENDICES

APPENDIX A

Case Studies Illustrating the Cooling Access–Energy Access Nexus

ESMAP'S IMPACT

In 2021 alone, ESMAP's Efficient, Clean Cooling Program allocated a total of **$9 million** to help support COVID-19 response projects in 11 countries

In 2022, **$9 million** in grants allocated to over 15 countries to help strengthen health systems.

With a **$2 million grant**, 62 solar climate-friendly refrigerators are being operated in South Sudan; supporting services delivered to approximately 1.26 million people

Overall, ESMAP has budgeted $100 million in grants for the COVID-19 response: electrifying health facilities, supporting an energy access relief fund, and the deploying climate- friendly cold chains to deliver vaccines

Climate-Friendly Vaccine Cold Chains in Mongolia

The Challenge

Vaccination of the poorest and most remote populations has often been a challenge. Vaccine cold chains require substantial energy and seldom reach rural areas. Meanwhile, COVID-19 placed newfound importance on the importance, and difficulty, of extending vaccine cold chains.

Country Context

Mongolia's rural-urban divide is particularly extreme: The country, which has a vast geographical area, covering over 600,000 square miles, has a relatively small, but widely dispersed, population. Nearly a quarter of Mongolia's 3 million population are nomadic pastoralists.

Vaccine cold chain storage in Mongolia had been a challenge before COVID-19. The existing central vaccine storage facility in the capital, Ulaanbaatar, could only hold 600,000 doses of vaccines and was already inadequate for storing routine childhood vaccines. Nor was it equipped to maintain the ultralow temperatures required for storing mRNA COVID-19 vaccines, such as those from Pfizer and Moderna, which required storing at –20°C to –80°C (–4°F to –112°F).

The inadequacy of cold storage made effective COVID-19 vaccination a challenge for Mongolia, given vaccine efficacy requires storing them at appropriate temperatures from manufacturing until administration. Inadequate cold chain infrastructure could result in vaccine wastage due to loss of potency, causing financial and health implications.

Response

When the COVID-19 pandemic began, the Energy Sector Management Assistance Program (ESMAP) swiftly reoriented its activities and shifted priorities to help mobilize technical and financial resources to support vaccine deployment. In partnership with the Mongolian government and other members of the World Bank's COVID-19 Vaccine Delivery Taskforce, ESMAP upgraded the country's cold chain storage capacity and redesigned the central vaccine storage.

In August 2021, Mongolia opened a new central vaccine facility equipped with over 10,000 pieces of energy-efficient, modern equipment. The central facility, whose storage capacity is four times the old facility's, can now store a minimum of 2–3 million vaccine doses. As of March 2022, Mongolia had administered roughly 5.5 million doses of COVID-19 vaccines—enough to have vaccinated over two-thirds of the country's population with two doses and over a third with an additional booster dose, according to the World Health Organization in Mongolia.

Lessons Learned

- Infrastructure projects can be more impactful and economical if they **integrate energy-efficient** and **climate-friendly** features **from the beginning** rather than retrofitting. Mongolia took advantage of the situation to create an energy-efficient facility with low greenhouse gas emissions and potential for future solarization.
- **Access to technical expertise** and financial resources is crucial for implementing climate- friendly cold chain systems. ESMAP was significant in providing technical advice, expertise, and grants to support the design and construction of Mongolia's central vaccine storage.
- **Collaboration and partnership** between international organizations like the World Bank, ESMAP, and the United Nations Children's Fund, and the Mongolian government are essential for successful project implementation. Close stakeholder coordination will enhance climate-smart aspects and ensure the storage facility has an efficient design and functionality.

Energy Efficient Cold Storage for Agriculture in Rwanda

The Challenge

Rwanda lacks adequate storage and processing infrastructure, including limited cold storage access, due to limited agricultural value chain development. Smallholder farmers and even medium-sized operations predominantly rely on basic off-the-ground storage facilities or those owned by cooperatives. These facilities lack temperature control, apart from other modern amenities. Establishment of unbroken cold chains for perishable commodities such as fish, meat, dairy, and horticulture produce faces hurdles, resulting in persistent, high postharvest losses. Grid- and solar-powered cold storage facilities are few and far between, and experience low operational and utilization rates. Underutilization results from a combination of factors: unreliable operation, concerns over expense, limited access, and unfamiliarity with the benefits of cold storage.

Country Context

Continued urbanization in Rwanda is expected to bring about significant changes in the agricultural sector. By 2050, more standardized and processed food will be in greater demand among the urban population (70 percent of the overall population) due to their higher income and shifting food preferences. However, this transition poses challenges for existing domestic supply chains, potentially increasing food imports and putting pressure on foreign currency reserves. Nonetheless, it also presents opportunities for securing rural agricultural livelihoods, expanding domestic value chains, diversifying away from traditional food staples, and adding further value across the agriculture and food system. Satisfying the local market's demands can pave the way for penetrating regional and international markets.

Rwanda has had inadequate storage and processing infrastructure due to the limited development of agriculture value chains. Access to storage, including cold storage, is limited, especially for perishable commodities such as dairy and horticulture produce. This lack of a robust cold chain system not only leads to high production losses—estimated at 40 percent per year—but also affects the quality of locally supplied products. This compels premium hotels and airlines to rely on imports from formal suppliers abroad instead of sourcing locally. Addressing these storage and processing limitations is essential to improve production efficiency, reduce losses, and make the agricultural sector more competitive in meeting the growing urban population's demands.

Response

The program comprised two successive rounds of ESMAP-funded technical assistance (TA) for improving cold chain infrastructure in Rwanda. The first TA focused on diagnosing the current situation of cold chains in the horticulture value chain. It assessed the adoption barriers to the existing cold storage technologies, conducted a stocktake of international experiences, and recommended a deployment road map for energy-efficient and effective cold chains. The second TA followed up on these recommendations and aimed to increase the uptake of cold storage facilities through an information campaign and implementation support. It targeted small- and medium-sized farmers, agribusinesses, and stakeholders in the value chain. Recommendations included addressing technology gaps, establishing private sector–driven management, developing standard operating procedures for postharvest handling, increasing affordable access to finance, and adapting regulations to align with government priorities.

The TA provided interventions to raise awareness of the benefits of climate-friendly and energy- efficient cold chain facilities and proposed operation and management models for the targeted areas. The aim was to increase the utilization of facilities with sustainable management and maintenance mechanisms. Specific models included private business management, cooperative management, and district management. Technology adoption was supported by various fee payment options, such as pay-as-you-store, monthly flat fee, and medium- to long-term rental. The assessments conducted informed the models' design and payment options tailored to each district. The objective was to make the cold chain infrastructure in Rwanda more efficient and effective, in turn supporting the growth of the agriculture sector and addressing the increasing demands of the domestic and potential regional and international markets.

Lessons Learned

- Establishing and implementing **standard operating procedures** for postharvest handling could significantly reduce food losses and ensure consistency in quality and supply across different food systems and market types.
- **Alternative management models**, including private sector–driven and cooperatives, **could significantly improve the utilization** and sustainable operation of cold chain infrastructure in rural areas.
- A conducive **regulatory environment**, which encourages **shifts in consumer preferences** toward meat and dairy products, can help to spur widespread utilization of cold chain infrastructure by small- and medium-sized farmers.

Solar-Powered Service Delivery in South Sudan

The Challenge

South Sudan's fragile health system—shaped by conflict, limited government funding, shortage of qualified health care professionals, inadequate infrastructure, and a lack of essential medical supplies—is mirrored in rural electrification struggles. Health care services in South Sudan are thus often subpar, leading to high under-five, neonatal, and maternal mortality rates.

Country Context

South Sudan's history has been marked by years of war and political instability, which have greatly affected its citizens' ability to access medical care. Since gaining independence from Britain in 1954, the country saw three successive wars. These prolonged conflicts have severely impeded health care development, posing significant barriers to the delivery of quality medical services.

The wars' effects are evident in the limited government funding for health care, leading to resource shortage for health care facilities, equipment, and medications. Especially rural health care suffers further constraints due to the scarcity of qualified health care workers. This scarcity is because professionals have been displaced or conflicts took their lives. Medical care delivery to remote areas is made even more challenging by an underdeveloped physical infrastructure, including a lack of electricity and safe water. This leaves a large part of the population without adequate access to health care for extended periods, especially during the annual heavy flooding season, when transportation becomes severely restricted. Tackling these obstacles and rebuilding the health care system is vital for improving the health outcomes for and well-being of South Sudan's population.

Response

The World Bank–funded COVID-19 Emergency Response and Health Systems Strengthening Project supports health service delivery in three states in South Sudan. The project's objectives are to prevent, detect, and respond to threats posed by COVID-19 and increase access to an essential package of health and nutrition services.

As of June 14, 2023, the project has installed 70 solar direct drive (SDD) refrigerators and four solar power systems for rural clinics. Also, project financing has supported the procurement of complimentary equipment, including an essential 805 cold boxes and vaccine carriers, which are used alongside solar-powered vaccine refrigerators to extend the vaccine cold chain and distribute medication directly to communities beyond the immediate vicinity of each solar- powered clinic. An additional $1.5 million for installing SDD refrigerators and solar power systems has been provided, based on the success of the original ESMAP grant.

Although it may appear modest, the expansion of cold chain infrastructure has been fundamental to accelerating COVID- 19 vaccination. **This has enabled vaccinating 67.46 percent of the target population, one of the highest COVID-19 vaccination rates in the East Africa region.** This expansion has also created essential infrastructure to support the expansion of basic childhood immunization.

Lessons Learned

- Equipment installation revealed **the importance of careful seasonal planning** for equipment distribution in **rural areas**, including budget allocation, procurement, and detailed distribution plans.
- **Resource allocation should be flexible to adapt to evolving, fragile, and rural contexts.** In- field assessments of solar power equipment revealed higher budget requirements and greater needs than initially estimated, whereas the cost of SDD refrigerators was lower than expected.
- Close **attention should be paid to equipment and power supply needs in rural areas**, considering the challenges posed by the terrain, infrastructure limitations, and changing requirements. This is vital to ensure efficient distribution, installation, and availability of essential health care equipment.

Cooling the Countryside with Solar in Pakistan

The Challenge

In rural Pakistan, electricity shortages continue despite high overall access levels, and electricity infrastructure remains inadequate. However, despite hindrances to the adoption of solar power solutions, rural residents are increasingly turning to solar power as a viable alternative to unreliable and expensive grid electricity. The climate conditions also necessitate space cooling in homes and microenterprises, not only for comfort but also as an essential part of a healthy environment, especially during the summer monsoon season. This demands optimizing and combining solar power supply components with high- efficiency (solar/direct current [DC]) fans.

Country Context

Climate change poses a dire threat to Pakistan, as evidenced by the devastating impact of the 2022 floods. There is mounting evidence of climate change already worsening severe natural disasters, such as floods, heat waves, and droughts, which have the potential to disrupt the energy sector, cause energy shortages, and exacerbate existing challenges. Combating climate change necessitates generating clean energy with energy-efficient appliances, to not just mitigate greenhouse gas emissions but also reduce vulnerability to the impacts.

The rural off-grid solar market, which often relies on component-based systems, is dominated by inferior and inefficient systems. The lack of proper infrastructure and consequent electricity shortages have created a demand for solar systems and solar power appliances even in “under-the-grid” areas, with unreliable electricity access. This exacerbates the need for efficient appliances, such as DC fans, to optimize the energy available from solar home systems (SHSs).

Response

The Sindh Solar Energy Project (SSEP) aims to expand electricity access in the Sindh province by providing affordable and reliable off-grid SHSs to 200,000 households. The program identified that creating a sustainable market for high- quality SHSs required bundling high- efficiency fans with SHSs to meet users’ cooling demands.

The program required SHSs to be verified by the World Bank–funded VeraSol quality assurance program and fans to meet the sister Global LEAP program’s performance benchmarks.

The SSEP thus assured access to reliable off-grid clean energy and sustainable cooling solutions through a program design that subsidized their cost, facilitated import through bulk procurement, and established a network of last-mile distributors to reach rural consumers. The inclusion of efficient DC fans in SHS kits allowed households to optimize their power consumption and better utilize the available solar energy. This made the project’s offerings more practical and relevant for the target population. By providing cooling solutions alongside electricity access, the project aimed to improve the overall quality of life for the households in Sindh and enhance the sustainability of the implemented solar energy solutions.

Lessons Learned

- **End users' needs must be addressed** in project design. In the SSEP, this was achieved through developing **SHS packages tailored to meeting users' demands, including cooling with fans**. This enhanced the relevance and adoption of SHSs.
- **Simplicity must be emphasized** in project design and implementation. **Simplified processes improve implementation efficiency** and scalability. Overly complex and cumbersome processes can hinder implementation progress and create barriers for project scale-up.
- There should be **reliable product/equipment supply.** A steady supply of high-quality SHSs is crucial for developing a sustainable market. **Focus on reliable supply chains** is crucial to have readily available products to sell before raising awareness among consumers and gaining and maintaining their confidence.

APPENDIX B

Business Models for Rural Cooling

TABLE B.1

Business Models for Off-Grid Cooling in Rural Areas

BUSINESS MODEL	FEATURE AND SECTORAL USE	OWNERSHIP	MARKET MOBILIZATION	KEY PROS	KEY CHALLENGES	EXAMPLES
Direct Purchase	A customer purchases cooling equipment from a seller after full payment. An intermediary pays for the equipment and donates to end users or end-user groups (such as farmer producer organizations or cooperatives). Well suited for residential space cooling, storage and space cooling for health care, and agricultural enterprises (micro, small, and medium enterprises).	A single end user, or a customer or organization serving multiple end users	Dealers/ suppliers find customers	1. Easy transaction	1. Requires high up-front investments 2. More suitable for intermediaries serving low-income farmers, or middle- and higher-income groups or enterprises with high purchasing power	EcoZen (India) selling to farmer groups, the government, and intermediaries such as the SELCO Foundation.
Pay-As-You-Go (PAYG)	A customer purchases a cooling appliance/ service on a prepaid plan, with a small incremental pay to the supplier. It is popular in the off-grid solar energy sector. The model relies on: 1. Hardware and software integration, 2. Product distribution and sales, 3. After-sales service, and 4. Secured working capital financing to keep the business running while selling Well suited for cold storage productive use appliances in agriculture. It can benefit farmers, households, and microenterprises.	Service provider in the case of a service; in the case of products, end users once repayment is done	Dealers/ suppliers find customers	1. Affordable for customers 2. Offers last-mile delivery 3. Scalable 4. Works well in off-grid settings	1. Service provider requires significant working capital 2. Risk of payment recovery 3. Needs advanced management systems for digital payment and inventory	Koolboks offers cooling services through small payments in Nigeria and supplies distributors in East and West Africa.
Cooling as a Service (CaaS)	A cooling service provider delivers refrigeration services in return for a fee as per the customer's usage. The service provider invests in infrastructure and is responsible for operation and maintenance (O&M) costs. Well suited for storage in the agricultural and health sectors (vaccine, medicine storage).	Service provider	Service providers find customers	1. Lowers up-front costs for consumers 2. Encourages energy-efficient technologies 3. Higher profit margins for service providers with lower O&M costs 4. A purely market-based model requiring very little regulatory support	1. Payback for investors could be slow 2. Requires extensive service networks 3. High risk of low-income consumers defaulting on payments	ColdHubs in Nigeria offers storage services to farmers through solar-powered walk-in cold rooms. Storage is priced at approximately US$0.50 per day per 20-kilogram box, and the facilities generate approximately 5.5 kilowatts of solar electricity to maintain a temperature of 5°C (U4E 2021).[a, b]

				5. Fixed assets can be securitized to generate a revenue stream 6. Applicable to the off-grid sector		SokoFresh in Kenya offers postharvest cooling to smallholder farmers. MediCool has helped reduce the burden on public health infrastructure and improved health care access. It provided solar fridges to clinics, maternity homes, and immunization centers in Africa.
On-Bill Financing (OBF)	A seller provides services/sells products to a customer against a utility bill as the repayment vehicle. This model is commonly used by grid/off-grid energy service providers. On-bill lending has been used for the past 30 years to encourage the uptake of clean energy improvements. On-bill programs work best when there is a cooperative utility. Suitable for space cooling, agriculture storage, as well as health care facilities.	Buyer (utility/end consumer)	Service providers use utilities' customer base	1. Makes cooling accessible to low-income users 2. Up-front capital provided by a third party (bank/distribution company/public or private agency), not the utility 3. Lower cost of loan for sellers 4. Streamlined process through utilities' existing relationship with consumers 5. Easier to reach more consumers through utilities	1. Repayment allocation (i.e., who is paid first) is an issue when customers pay their bills partially 2. Risk to lenders 3. More suited to consumers with a steady income source 4. Not suited for regions without a major utility present	ECOFRIDGES in Senegal and the Economic Community of West African States (ECOWAS) in Ghana offer energy-efficient refrigerators or cooling solutions for customers to purchase, respectively, through utility bill payment or wage deduction.[c]
Dealer Financing and Leasing	A financial institution funds a cooling service enterprise through a finance leasing agreement, where the cooling system is used as collateral. Suitable for space cooling, agriculture, and health facilities.	Financier/service provider after full repayment	Service providers are responsible for finding consumers	1. Affordable for end consumers 2. Service providers relieved from the burden of up-front investment 3. Incentivizes the use of high-quality/energy-efficient equipment 4. Encourages O&M improvement, in turn increasing profit margins 5. Complements other business models—ESCOs, bulk procurement, and so on.	1. Repayment default by consumers 2. Risk to lenders	The Rwanda Cooling Initiative (R-COOL), launched in 2019, will use the Coolease model and OBF to accelerate access to climate-friendly cooling and refrigerators.

(*continues*)

TABLE B.1

Business Models for Off-Grid Cooling in Rural Areas (*Continued*)

BUSINESS MODEL	FEATURE AND SECTORAL USE	OWNERSHIP	MARKET MOBILIZATION	KEY PROS	KEY CHALLENGES	EXAMPLES
Energy Service Companies (ESCOs)	A third party (financier) invests directly through an ESCO, which enters into an energy performance contract (EPC) with a client. The EPC guarantees energy and monetary savings. The ESCO repays financing costs through client fees and derives income through energy savings. Suited to the agriculture and health sectors, although usually large enterprises.	ESCO/client after full repayment	ESCOs have to identify and reach out to clients	1. Lower risk for clients 2. Staggered payment by customers 3. Applicable to multiple cooling technologies 4. Energy savings 5. Requires energy audits, which can help clients understand the energy efficiency of their built environment	1. High up-front investment required for the ESCO 2. Risk to lenders since energy efficiency savings can be uncertain 3. Requires client awareness on savings due to energy efficiency 4. Engineering, procurement, and construction (EPC) can be complex 5. More suitable to clients with high energy consumption	Synergy Efficiency Solution (SES), an ESCO, invested in achieving energy reductions for Adi Husada Hospital in Surabaya, Indonesia. The project generated 40 percent energy savings and reduced hospital bills by 45 percent.
Community Cooling Hubs	This model, which is well suited to rural needs, works on the demand aggregation principle through the servitization of cooling solutions. These solutions—selected as "game changing solutions" for the 2021 United Nations Food Systems Summit—serve as hubs for agriculture cold storage in a manner similar to ColdHubs, but they can serve a broader variety of cooling needs, for example, vaccine storage or protection during heat waves. Suited for agriculture storage and hospital cold storage. The resources to understand market suitability include the Cool Coalition NCAP (national cooling action plan) data framework for agriculture, the Sustainable Energy for All (SEforALL) Cooling Needs Assessment, and the Africa Centre for Sustainable Cooling and Cold-Chain.	Service provider	Service providers have to find customers	1. Cooling access for more users—community level 2. The PAYG model is the best. It makes access affordable for rural communities	1. Requires a needs assessment survey 2. Requires awareness creation 3. Requires good volume of goods and commodities to be profitable 4. Requires significant capital 5. Still at the conceptualization and pilot stage	A needs assessment study was conducted on community cooling hubs in India. It found that multifunction hubs were the most appropriate for storing agricultural and dairy produce, meeting the thermal comfort cooling needs of surrounding communities, and storing vaccines.

Source: USAID 2021; IRENA, IEA, and REN21 2020; Nain and Bhasin 2022; ACEEE 2017; U4E 2021; IEA 2018; Count on Cooling 2021; Debnath et al. 2021.

Note: [a] In 2019, Nigeria's ColdHubs reported having increased the household income of some of the country's smallholder farmers, retailers, and wholesaler clients by 100 percent from US$60.00 to US$120.00. It created 48 new jobs for women and helped preserve over 20,000 tons of fresh fruits and vegetables.

[b] The Basel Agency for Sustainable Energy (BASE) has supported the piloting of many CaaS approaches, including in commercial buildings in India and Colombia, and a data center in Singapore. The Caribbean Cooling Initiative (C-COOL) is developing a CaaS mechanism in the Dominican Republic with support from U4E, K-CEP, and BASEL (U4E 2021).

[c] As of May 2022, ECOFRIDGES generated 17,436 megawatt-hours in energy savings over equipment lifetime via reduced residential electricity demand and saved 16,445 tons of carbon dioxide emissions

APPENDIX C

Quality Assurance Standards of Off-Grid Cooling Appliances

Adoption of efficient appliances requires policy support, including for appliance labeling and information disclosure regarding energy efficiency. Policy support should also promote and ensure certification, quality assurance testing, and incentive channeling only to cooling appliances meeting performance benchmarks or standards. Based on VeraSol's success in developing and implementing Quality Assurance (QA) , the activities below have been proposed as critical to build an effective QA approach for off-grid cooling products. These activities focus on the design and implementation of a QA framework.

Consultation and needs assessment. There are numerous off-grid cooling solutions for specific use cases. Examples of these include solutions for domestic, light commercial, and institutional space cooling, as well as solutions for cold storage and cold chains for agriculture, dairy, fishery, and even livestock produce. The VeraSol team understands end users' cooling needs and the unique market barriers in each local context. This helps them target and prioritize specific cooling technologies more effectively and design suitable QA frameworks to address needs and barriers.

Test method and standards development. Based on consultation feedback, the VeraSol team reviews existing test methods, identifies gaps, and revises or develops new test methods for off-grid cooling technologies. The team has been maintaining the Global LEAP Off-Grid Refrigerator Test Method (VeraSol 2021), and is developing a quality standard to evaluate refrigerators sold with solar energy kits. These documents can serve as a starting point to develop further test methods and standards for other cooling technologies.

Field testing and end user research. Field testing activities are required to evaluate how off-grid cooling products perform in their intended environments and how end users' behavior and interactions with products affect performance and durability over time. VeraSol's process involves field testing on selected cooling products to validate the laboratory testing procedure. This ensures the testing conditions mirror real-life conditions. As part of field testing, VeraSol also proposes to conduct end-user research to ensure that quality standards match consumers' needs.

Certification implementation. For quality standards to be effective, there must be a process to verify whether products meet the standards. Much like the certification process for solar energy kits, VeraSol proposes creating a pipeline process to facilitate testing, verifying product quality, issuing certificates, and maintaining a list of certified products on the VeraSol Product Database.

Technical assistance (TA). Policymakers and other market stakeholders must work collaboratively with, and provide direct TA to governments, institutions, and programs to help them utilize quality standards and adopt and implement them effectively. TA may include creating customized procurement guidelines and other tools based on quality standards for faster adoption of high-quality cooling technologies.

Capacity building. Warranty and after-sales servicing are two key challenges given the high technical complexity and cost of replacing refrigerators and other cooling solutions. A strategy to support capacity building and after-sales services is therefore essential, and could include training for installation and repair technicians, analysis of models for delivering spare parts, analysis of models for successfully providing after-sales service and warranty support, advisory support to companies to successfully develop and provide after-sales and warranty support services, and related activities. These will help build local capacity, help distributors and manufacturers address challenges on site, and foster appliance reparability.

APPENDIX D

Technical Annex for Different Cooling Technologies

COOLING TYPE	NAME	USAGE	TECHNICAL DESCRIPTION
Passive	Passive house insulation/ wall shading/ improved air circulation and ventilation	Cooling for homes, health centers, schools etc.	Using passive cooling technology for house cooling or space cooling, this is combines insulation with shading technology/construction materials (ClimateBiz 2021).
Passive	Vaccine transport cooler	Can be used to store vaccine, blood, and medical supplies for short time periods utilizing insultation and frozen 'ice or coolant packs' (which need active cooling prior to use	Cold boxes, vaccine carriers and coolant packs are used for keeping vaccines cold during transportation. In comparison with cold boxes, vaccine carriers have a smaller volume, suitable for use by health workers during immunization campaigns and out-reach services (UNICEF 2021).
Active	Ventilation	Air circulation for factories, and warehouse	One of the best ways to manage the risks of airborne contamination in warehouses and factories is though industrial mechanical ventilation systems (US DOE n.d.).
Active	Space cooling fan for rooms	Cooling rooms, and space cooling — sizes range from tabletop, free standing or wall/ ceiling mounted.	Cooling fans play a crucial role in circulating air inside buildings, making fresh air in place of hot air (Efficiency for Access 2021g).
Active	Water based cooler	Cooling rooms and space cooling	Portable Evaporative Air Cooler combines a fan driving water from a reservoir through a mesh or sponge to cooler the air. Variations can spray fine mist into a room. An evaporative cooler (also known as evaporative air conditioner, swamp cooler, swamp box, desert cooler and wet air cooler) is a device that cools air through the evaporation of water. Evaporative cooling exploits the fact that water will absorb a relatively large amount of heat to evaporate. The temperature of dry air can be dropped significantly through the phase transition of liquid water to water vapor (evaporation). This can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of building occupants.
Active	Solar-Powered Ice Making	Wide variety of uses from space cooling to refrigeration of produce and beverages.	Use of photovoltaic power for conversion of ice to water and can be applied for a variety of applications where the ice is used to cool air for space cooling, directly to cool produce (such as fish) or as an 'ice battery' to store cold for refrigeration without electro-chemical batteries (https://en.wikipedia.org/wiki/Ice_storage_air_conditioning).

(*continues*)

COOLING TYPE	NAME	USAGE	TECHNICAL DESCRIPTION
Active	Kitchen exhaustion system	Kitchen heat exhausting after cooking	An exhaust hood, also called extractor hood, or range hood is a device that has a mechanical fan hanging above the stove or cooktop in the kitchen. It helps to remove odors, airborne grease, fumes, combustion products, smoke, heat, and steam from the air by evacuation of the air and filtration (INSTA-BRITE n.d.).
Active	Radiant cooling	Indoor house cooling and heating, school, or health centers	Typically designed in conjunction with radiant heating, radiant cooling systems circulate cooled fluid through the same network of PEX pipe used for heating, creating a cooled floor, wall or ceiling that can evenly absorb sensible heat energy. This includes radiant energy from solar gain, people, equipment, lights, and computers, in addition to convective heat transfer from the air (Office of Energy Saver n.d.).
Active	Ice based air conditioner	Can be used as portable air cooler in boat, airplane, or any other vehicles	The Icebox is a portable air conditioning system, for car, boat, or airplane. Exhaust Air Hose for extended reach cooling (Green Building Advisor 2009).
Active	Solar powered cold rooms	Most widely used for vegetables, horticulture, dairy, fisheries and poultry refrigeration in weak or off-grid applications. Also including applications in vaccine/ medical cold chains for both human health and veterinary applications.	Solar powered cold rooms have the potential to significantly improve livelihoods for smallholder farmers and small traders by reducing the post-harvest loss of crops, increasing profits by boosting farmers' bargaining power at the marketplace, and unlocking regional and international markets to smallholders in remote rural areas (Efficiency for Access 2021b).
Active	Solar powered refrigeration	Most widely used for vegetables, horticulture, dairy, fisheries, and poultry refrigeration in weak or off-grid applications. Including applications in domestic or micro-enterprise circumstances for a wider range of produce. Also including applications in vaccine/ medical cold chains for both human health and veterinary applications.	Solar powered refrigerators utilize direct current (DC) components for use in varied domestic, micro-enterprise and fisheries, dairy or horticulture applications to save post-harvest loss, increase preservation of processed foods and sales of cold beverages, etc. in weak or off-grid areas (Efficiency for Access 2021f).
Active	Purpose built vaccine cold storage unit - SDD/Solar Direct Drive	Designed to store vaccine, blood, and medical supplies	These chilling units are unique in that they are designed and tested to keep vaccines, bloods, and medicines within appropriate temperature ranges. This is crucial for vaccine efficacy and patient protection (WHO 2017).
Active	Solar milk cooling with insulated milk cans	Can be used for milk chilling as a low-cost decentralized alternative for famers of small herds instead of commercial milk chilling plants.	The milk cooling solution developed by the University of Hohenheim is based on a commercially available DC refrigerator, equipped with an adaptive control unit for its conversion to a smart icemaker. It operates depending on the availability of solar energy. Do it yourself — solutions for solar ice making are also possible (GIZ n.d.).
Active	Refrigerated truck or containers	Used to carry milk, vegetables, perishable food or medical suppliers	Vehicles combine active refrigeration with insulation in goods compartments from small vehicles to 40 ft refrigerated containers or 'reefers' for international transport which can even be self-contained. Ensuring that fish, fruit and vegetables, beverages, pharmaceuticals, and other temperature-sensitive goods are kept cold during transportation.

APPENDIX E

The Lighting Africa/Lighting Global Road Map to Off-Grid Energy Access

The World Bank has supported access to off-grid solar lighting and electricity through its Lighting Africa and Lighting Global programs for nearly 15 years, running its first pilot project in Kenya in 2009. At the time, off-grid solar electricity was a little-known and poorly trusted technology with limited applications but great potential. While the small solar home systems that were the main products available at the time could already transform individual lives—by providing clean, safe, and affordable lighting that could displace the harmful fumes of kerosene lamps—they were largely dismissed as inadequate as anything other than a stop-gap solution until the electric grid arrived.

Today, the applications powered by this ever-more ubiquitous technology encompass multi-light systems, solar home systems (SHS), and appliances—including those for cooling—while continuing to provide millions of students with safe bright lights to study by after nightfall. By 2021 an estimated 493 million people were using off-grid solar energy kits of various sizes, while the off-grid sector had attracted more than US$2.3 billion in investments and had also become generally accepted as playing a key role in achieving universal access to reliable, sustainable and affordable energy by 2030 (Sustainable Development Goal 7).

As an early off-grid pioneer, Lighting Global (which has evolved as a program expanding the scope laid out by Lighting Africa) led the way in supporting the sector's development from practically nonexistent to today's vibrant global market, which reaches hundreds of millions of the world's poor people who previously had no access to electricity through its support activities. While the program has continually fine-tuned its interventions to adapt to local needs, market dynamics, energy access priorities, evolving business models, and technological innovations, the broad strokes of the program's approach have demonstrated robust results across geographic regions and technologies, and can serve as a valuable roadmap to increase access to off-grid cooling technologies as well.

Lighting Global's approach includes the following areas of interventions along the supply chain:

- **Market intelligence and knowledge sharing**: In order to understand consumer needs, preferences, and ability to pay, market bottlenecks and distribution channels, Lighting Global conducts extensive market research and shares the findings to inform business decisions and policy interventions. In addition to producing dozens of in-depth reports looking at different country contexts and technologies, Lighting Global, together with the Global Off-Grid Lighting Association (GOGLA), produces semi-annual reports that track sales and impact results by country, region, and worldwide, as well as the flagship biennial Off-Grid Solar Market Trends Reports (MTRs), where sector trends are explored in detail. These are the go-to source of sector information for investors, industry members, policymakers, and other stakeholders. Making available these documents, together with convening knowledge exchange opportunities—including webinars, training programs, and the premier Off-Grid Solar Forum and Expo held every two years—encourage rapid sector growth, through collaboration and idea exploration.

- **Consumer education and awareness building**: Lack of awareness and trust in the sector hampered early demand for off-grid solar lanterns, and made financial intermediaries baulk at giving loans. Lighting Africa/Global thus promoted the integration of consumer education and awareness building into projects to build demand. The focus of this awareness building has evolved from a general introduction into off-grid solar technology to help consumers and financial backers identify quality products, grow awareness of the wide range of applications now powered by off-grid solar, and identify financing opportunities.
- **Policy engagement**: Through research, hands-on lessons learned, and exchange with partners, Lighting Africa/Global has identified a number of market bottlenecks and identified approaches to unlock market potential. The programs' off-grid experts are thus embedded directly into World Bank operational teams to design energy-access off-grid project components and help advise governments on improving the off-grid solar enabling environment. These market conditions can be improved through policies and regulations, fiscal incentives, access to finance, adoption of quality standards, consumer protection and more.
- **Quality assurance**: In order to safeguard investments and ensure impacts while instilling confidence in consumers and financial intermediaries, Lighting Africa/Global developed quality standards for off-grid solar products, which have been adopted by the IEC as a reference point for quality assurance and now inform national policy for more than 20 governments. Since February 2020 VeraSol has been maintaining and expanding Lighting Global's quality assurance work, maintaining an up-to-date list of quality verified products.
- **Access to finance**: Financial constraints continue to be among the most significant challenges to the off-grid solar sector—contributing to bottlenecks all along the supply chain, as importers, retailers, and distributors all need significant working capital. Without financing, consumers are also frequently priced out of products, particularly larger appliances such as those supporting productive use in agriculture. Lighting Africa/Global supports both supply-side and end-user financing through financial instruments including lines of credits, results-based financing, and end-user subsidies to expand access.
- **Capacity building:** As a fairly new and still developing sector, Lighting Africa/Global has helped to improve government capacity in public sector energy access agencies, as well as provided key business support. On-the-ground experts have worked with governments on supporting technical assistance facilities, and worked with companies to fine tune business models.

The details of these approaches differ depending on the context and technology they are supporting, but have formed the backbone of Lighting Africa's and Lighting Global's successful approach for more than a decade of interventions. Many lessons can be learnt from this experience and parallels can be seen with today's challenge of bringing access to sustainable cooling as the next frontier through rural electrification efforts for the same populations who have been targeted with solar lighting initiatives and more recent efforts to introduce the benefits of productive uses of solar energy, such as cooling of homes, workplaces, institutions, produce and vaccines. These main intervention areas have proven successful and can be seen as the essential pillars on which a holistic, sector wide approach to transforming markets of advancing access to rural cooling solutions alongside sustainable off-grid electricity access.

Source: Lighting Global, World Bank, and ESMAP 2023.

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