GOGLA

The Voice of the **Off-Grid Solar Energy** Industry

Decentralised Solar Refrigeration: Opportunities in the Livelihood Appliances Market in India

January, 2021

intellecap

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Acknowledgement

This report is the result of a study carried out by Intellecap and supported by GOGLA. It aims to generate evidence-based information on the potential of off-grid solar refrigeration across key market segments (healthcare, households, micro-enterprises, farm-gate and dairy) in India. It also maps the existing ecosystem of the off-grid solar refrigerator sector and provides recommendations to support the market development of this sector.

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We welcome your feedback on this effort and encourage you to reach out to the team with your questions and comments through www.intellecap.com or by emailing at energy@intellecap.com

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List Of Abbreviations

Abbreviation	Expanded Notation
AC	Alternative Current
AHIDF	Animal Husbandry Infrastructure Development Fund
AIF	Agriculture Infrastructure Fund
BEE	Bureau of Energy Efficiency
BIRD	Banker's Institute for Rural Development
BIS	Bureau of Indian Standards
BOLT	Build-Operate-Lease-Transfer
BOT	Build-Own-Transfer
CaaS	Cooling-as-a-Service
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CGTMSE	Credit Guarantee Fund Trust for Micro and Small Enterprise
CSR	Corporate Social Responsibility
DAC	Department of Agriculture Cooperation and Family Welfare (DAC&FW)
DC	Direct Current
DCS	Dairy Cooperative Societies
DF	Deep Freezer
DG	Diesel Generator
DSBM	Dairy Business Hub Model
EMI	Equated Monthly Instalment
eVIN	Electronic Vaccine Intelligence Network
FCDO	Foreign, Commonwealth and Development Office
FLCTD	Facility for Low Carbon Technology Deployment
FPO	Farmer Producer Organisation
GA	General Areas
GEF	Global Environment Facility
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GOGLA	Global Off-Grid Lighting Association
HMNEH	Horticulture Mission for North East and Himalayan States
IBA	Indian Banks' Association
ICAP	India Cooling Action Plan
IFAF	Innovation in Food and Agriculture Fund
IFC	International Financial Corporation
ILR	Ice Lined Refrigerators
KII	Key Informant Interview

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Abbreviation	Expanded Notation
kWh	Kilo Watt Hours
kWp	Kilo Watt Peak
MFIs	Micro Finance Institutions
MIDH	Mission on Integrated Development of Horticulture
MNRE	Ministry of New and Renewable Energy
MoFPI	Ministry of Food Processing Industries
MPPT	Multi Point Power Tracking
MT	Metric Tonne
NABARD	National Bank for Agriculture and Rural Development
NBFCs	Non-Banking Financial Corporation
NGO	Non-Government Organizations
NHM	National Health Mission
OPEX	Operational Expenditure
PACS	Primary Agricultural Credit Societies
PCM	Phase Change Material
PHC	Primary Health Centre
PPP	Private Public Partnership
QA/QC	Quality Assurance/Quality Control
RE	Renewable Energy
SAM	Segmented Addressable Market
SDD	Solar Direct Drive
SDG	Sustainable Development Goals
SHC	Sub-Health Centre
SNA	State Renewable Energy Development Agencies
SRLM	State Rural Livelihood Mission
SWB	Solar with Battery
TAM	Targeted Addressable Market
ToT	Training of Trainers
TOTAL	All Fruits & Vegetables
TSS	Thermal Storage System
UN	United Nations
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
USD	United States Dollars
WHO	World Health Organization

Executive Summary

Context

Off-grid solar appliances, and refrigerators more specifically, can play a transformative role in improving people's health and socio-economic statuses. Appliances contribute to achieving SDG 1 (poverty reduction), SDG 2 (food security), SDG 3 (health and well-being), SDG 4 (education), SDG 7 (clean energy) and SDG 8 (jobs and entrepreneurship).[1] According to The World Bank, there is growing evidence that affirms a link between socio-economic benefits and access to affordable and sustainable energy.[2] In India, the reliability of grid-based electricity remains a challenge, despite an electrification rate of 99.93%.[3] The Electricity Supply Monitoring Initiative (ESMI) data shows that rural areas in several states face frequent power cuts and voltage fluctuations on a daily basis. In 2019, 48% of the ESMI locations (65 rural and 126 urban areas) lacked electricity supply for more than 15 hours in the month of January.[4] Voltage fluctuations and unreliable grid connection can damage or limit the use of appliances by households and micro-enterprises. Conventional AC refrigerators require a continuous supply of power, which makes them unreliable for use with intermittent grid connections, especially in the case of cold chain infrastructure and vaccines, which require strict temperature control. Thus, there is an opportunity for DC refrigerators with batteries, which would make efficient energy appliances for productive uses available in in rural areas, supplementing existing grid access. One of the most beneficial and prominent productive use-cases is refrigeration, which contributes to SDG 1, 2, 3, and 8 directly.

In this context, GOGLA engaged Intellecap to examine the market potential for off-grid solar refrigeration in India. The overarching objective of this report is to generate evidence-based information on the potential of off-grid solar refrigeration for companies, policy makers/influencers and development partners. Recent studies suggest that there is growth in consumer demand for off-grid refrigeration in the household, commercial, and agricultural sectors. However, at present, the off-grid refrigeration market remains nascent. This is mainly due to the high upfront costs, low consumer awareness on the availability and benefits of the technology, limited understanding on handling of perishable agricultural and dairy produce, and poor market information.

The study identifies different market segments for off-grid solar refrigeration across households, micro-enterprises and small holder farmers. It also estimates the market size for business planning, and defines the overall ecosystem for promotion of off-grid solar refrigeration in India. The key market segments that have been considered for assessing the market potential are healthcare (vaccines), households, micro-enterprises, dairy (milk), and farm-gate (fruits and vegetables). For each of these segments, the study captures the market size estimate, existing business and consumer financing models, prevalent technologies, and key challenges and opportunities.

The methodology followed a step-by-step process for market assessment. This included a secondary literature review on refrigerator related discourse (including market studies, policies, programs, technology etc.), and primary stakeholder interviews with more than 40 ecosystem players. These methods shed light on the existing landscape of off-grid solar refrigeration, challenges and opportunities in each market segment. Intellecap also conducted a market estimation and cost modelling exercise.

[1] The State of the Off-grid Appliance Market; Energy for Access Coalition, UKAID; October 2019 (Link)
[2] Sustainable Development Goal on Energy (SDG7) and the World Bank Group; The World Bank; May 2016 (Link)
[3] Statistic is provided by the Saubhagya Dashboard, GoI (Link);
[4] Analysis Reports: ESMI Dashboard; Prayas Energy (Link)

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Market Outlook

The study finds that off-grid solar refrigeration offers a total addressable market (TAM) of USD 20.6 billion with a segmented addressable market (SAM) of USD 4.3 billion across five market segments in India. The division as per market segments is represented in Figure 2.

These market segments offer immediate opportunities for introducing off-grid solar refrigeration in weak-grid and off-grid areas, considering the need for reliable energy supply for productive use.

Figure 1: Snapchat of the market dynamics in five key market segments

Vaccine
- Market potential for refrigeration of vaccines at healthcare sector and chemists (for last mile delivery) as a result of COVID-19
- A time consuming and complicated tendering process discourages companies from applying
- Government is the largest buyer of vaccine storage for supply at PHCs and other institutions

Household
- Increasing demand for refrigerators from rural areas due to improved income and standards of living
- High upfront cost of technology and lack of consumer financing limits uptake by households
- NGOs/Foundations provide financial support to households for purchase of solar refrigerators

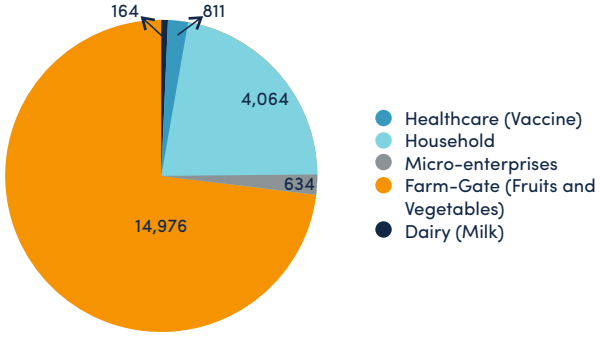
Micro-Enterprises
- Potential demand from shop owners to maintain perishable items (cold drink, cold water, ice cream, etc.)
- High upfront costs of technology and poor access to commercial finance are key challenges
- Along with retail sales, companies prefer partnership with large corporates for bulk sales

Farm-Gate
- Recent policies support the farm-gate off-grid refrigerator sector
- Majority of the cold storage supports single commodity - usually the potato; there is a need for multi-commodity storage
- To improve access for small holder farmers, lease/rent model has been piloted by few companies

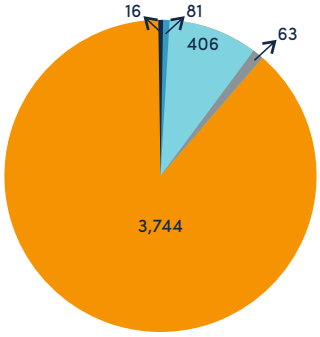
Dairy
- Increasing year-on-year milk processing requires an improved chilling capacity
- Highly unorganized sector; majority of the farmers sell milk to local milk collectors
- Direct sales of milk chilling units exist only for large federations and societies

Figure 2: TAM and SAM of off-grid solar refrigeration in India

Total Addressable Market of Off-Grid Solar Refrigerators (USD Mn)



Segmented Addressable Market of Off-Grid Solar Refrigerators (USD Mn)



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Healthcare (Vaccine)

In the healthcare segment, the total addressable market for off-grid solar vaccine storage is around USD 811 million. Across rural India, around 50% of the primary health centres (PHCs) either do not have a continuous supply of electricity or lack grid connectivity.[5] Several healthcare products (such as vaccines, biopharmaceuticals, blood banks, etc.) are temperature sensitive and need to be stored at temperatures ranging from -20°C to +20°C. An estimated 25% of vaccines are wasted due to improper cooling and poor supply chain management, which characterize the majority of rural areas.[6] Thus, it is important to provide proper refrigeration systems across the value chain to prevent vaccines from being wasted due to temperature differences. Further, there is a shortage of around 8,254 PHCs in India (as per Government of India norms that suggests availability of one PHC for every 30,000 citizens).[7] This accentuates the problem of health service delivery in rural areas. The states of Karnataka, Rajasthan and Uttar Pradesh have the highest potential for piloting off-grid solar vaccine storage. These states have the highest proportion of PHCs with unreliable electricity supply. Along with PHCs, refrigeration infrastructure is also required at sub-health centres, ambulances, and chemists for last mile delivery of vaccines. There is thus, an opportunity to deploy solar direct drive (SDD) refrigerators of 100-litre capacity to 20,900 PHCs, solar photovoltaic (PV) with battery (SWB) powered refrigerators of 270-litre capacity to 180,000 chemists, and solar vaccine carriers of four litres capacity to 153,650 SHCs and 24,850 ambulances. The segmented addressable market for off-grid solar vaccine storage is estimated at USD 81 million.

In India, the vaccine refrigeration market is mostly government driven and dependent on the availability of funding with respective government agencies. In a few geographical areas, NGOs and development partners are supporting local government to maintain and upgrade the vaccine refrigeration value chain. For example, the United Nations Development Programme (UNDP) is helping the Government of India to design and implement an Electronic Vaccine Intelligence Network (eVIN) in more than 521 districts, across 21 states and union territories.[8] The Central or State government procures vaccine cold storage units through a tender process. However, this cumbersome process involves delays in vendor selection and discourages their participation. This postpones the introduction of new technologies in the market. The ongoing pandemic (COVID-19) has intensified the need to upgrade the country's healthcare cold chain infrastructure. In this context, the government is also driving a significant push for the proper storage of vaccines under the ambit of the "Universal Immunisation Programme" and the "National Vaccine Policy".

[5] The State of Electricity Access for Primary Health Centres in India; Council on Energy, Environment and Water (CEEW); February 2019 (Link)
[6] Vaccine Wastage Assessment: Field Assessment and Observations from National stores and Five Selected States of India: UNICEF; 2010 (Link)
[7] Indian Public Health Standards (IPHS) Guidelines for Primary Health Centres; GoI; 2012 (Link)
[8] Web Article - Improving Vaccination Systems (EVIN); UNDP (Link)

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Households

The total addressable market for household off-grid solar refrigerators is USD 4.1 billion. Rural and semi-urban areas in India face inadequate supply of electricity due to weak or no grids. Around 40% of the rural households (from a sample of 10,049 households across four major states of Bihar, Uttar Pradesh, Rajasthan, and Odisha) do not receive 24x7 adequate and reliable grid electricity supply.[9] People living in off-grid and weak-grid communities have a particularly high need for refrigeration, mostly to address food storage issues. However, unreliable electricity supply with long power shortages impacts the reliability of AC refrigerators in rural areas. Further, there is low penetration of off-grid solar refrigerators due to poor affordability among households in India. According to the National Family Health Survey (NFHS)[10], in 2015-16, only 16.4% of rural households owned refrigerators. Out of the total 201 million rural households in India, only about 8% generate an income greater than USD 1,608 per annum (USD 134 per month).[11] Thus, households with lower income levels are a viable market for low-cost, high-quality, energy-efficient refrigerators, customised for rural, off-grid areas. In particular, Kerala, Uttar Pradesh, and Karnataka have been identified as the states with the highest potential for off-grid solar refrigerators, as they have a significant number of households without refrigerators and a high proportion of households with an income more than USD 1,608 per annum. The segmented addressable market for households is estimated at USD 406 million. Currently, the most common product size for off-grid solar refrigerators (without freezers) is between 50 and 99 litres, and the most common size for refrigerator-freezer combination units is between 150 and 249 litres.[12] According to the interviewed stakeholders, the most viable capacity of off-grid solar refrigerator for rural households is 150-litres.

There is a low penetration of solar off-grid refrigeration products among households despite direct sales via channel partners or support from NGOs/Foundations. Existing distributors of solar off-grid products (home lighting system, panels, batteries, etc.) are also key channel partners for solar off-grid refrigeration products. However, limited consumer awareness, poor brand recognition of off-grid solar refrigeration products (e.g. consumers prefer popular brands like Samsung and LG) and a lack of standardised certification and quality assurance impacts consumer confidence. This results in low adoption rates in the rural areas. It is expected that improved lifestyles of rural consumers can increase demand for off-grid solar refrigeration in the near future. Companies need to create awareness among both consumers, and policy influencers on aspects related to the availability and the economic and environmental benefits of the technology. This will help attain economies of scale and improve the commercial viability of products.

[9] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[10] National Family Health Survey; Ministry of Health and Family Welfare; GoI (Link)
[11] Social and Caste Economic Census 2011; GoI (Link)
[12] Off-Grid Appliance Performance Testing: Results and Trends for Early-Stage Market Development; Lai, E., Muir, S. & Erboy Ruff, Y; May 2019 (Link)

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Micro-Enterprises

In weak-grid and off-grid areas, the total addressable market of off-grid solar refrigeration for the micro-enterprises segment is USD 634 million. For this study, the micro-enterprises considered are rural 'kirana' stores that have a significant demand for refrigerators, as they stock chilled products, like water, beverages and food items. There is an increased demand for these products, particularly during the summer months. A study on rural electrification in India, found that only 65% of micro-enterprises (from a sample of 2,019 across 200 villages in the four states of Uttar Pradesh, Bihar, Rajasthan and Odisha) are connected to the electric grid.[13] Moreover, 40% of the surveyed micro-enterprises do not have 24x7 grid electricity supply. In India, there are a total of 9.44 million kirana stores, of which 3.78 million kirana stores (that amount to 40% of the total) are not satisfied with the grid electricity supply.[14] Currently, the majority of kirana stores use traditional clay coolers to keep products cooler than ambient temperature. Some stores also use AC refrigerators in weak-grid areas, with an expectation of uninterrupted supply of grid electricity. However, insufficient cooling due to poor electricity supply can lead to spoiled commodities. The use of off-grid solar refrigerators can reduce the potential losses incurred by kirana stores[15] by providing a reliable energy source for cooling. The most preferred customer segment is the 0.68 million large kirana stores (18% of total kirana stores[16]), which have inventories greater than USD 2,000. The optimum capacity of refrigerators for these stores is around 268-litres. Bihar, Rajasthan and Uttar Pradesh are key states for piloting solar off-grid refrigeration, as they have the highest number of kirana stores and about 40% of rural micro-enterprises do not get 24x7 reliable grid electricity supply. The segmented addressable market for off-grid solar refrigerators for micro-enterprises is USD 63 million.

Direct to retail channel is the preferred business model in rural areas for off-grid solar refrigeration. In this business model, existing distributors of other appliances and allied sectors (such as solar home system, solar panel, and electrical contractors) collaborate with manufacturers to introduce off-grid solar refrigerators in the market. These distributors have a well-established supply chain and after-sales service network in rural areas. Other business models include partnerships with NGOs/foundations and large corporates. For example, large organisations such as Amul, Coca-Cola and Mother Dairy provide refrigerators to small shop owners at a negligible cost (or sometimes, even free) and recover their investment from their product margins. However, high upfront costs for off-grid solar refrigeration technology (2-3 times of AC refrigerators) and limited options for consumer financing reduces the adoption of off-grid solar refrigerator technology in rural areas. To increase the adoption rate, companies can integrate their technology with other products such as mini-grids to offer a potential solution for meeting demand in off-grid areas. Companies can also target large retail shops and micro-food processing industries that require refrigeration for cooling produce and storing perishable items in areas with an irregular supply of grid electricity.

[13] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[14] Ibid
[15] Local Kirana Shops Offer Various Business Opportunities in Retail and Distribution Market in India; Mitsui & Co. Global Strategic Studies Institute; October 2018 (Link)
[16] Rural electrification in India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)

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Farm-Gate (Fruits and Vegetables)

India has a total addressable market of USD 15 billion for off-grid solar refrigerators used to store highly perishable fruits and vegetables at the farm-gate. Over the years, India has witnessed a marked increase in the consumption of perishable produce, especially fruits and vegetables. In 2018-19, the total production of fruits and vegetables was 284 million MT.[17] Currently, India has 8,186 on-grid/diesel refrigerators for storing perishable goods, with a total capacity of 37 million MT.[18] Around 75% of the total on-grid/diesel refrigeration systems in India are single commodity (mainly potatoes) and only 25% are multi-commodity cold storage facilities (majority of which are used for tomatoes and onions). The demand supply mismatch and inadequacy of appropriate farm-to-market logistics contributes to high food losses, especially in the case of perishable products. In 2018-19, the lack of adequate refrigeration infrastructure led to a wastage of ~5.6 million MT (~16%)[19] of highly perishable fruits and vegetables which require refrigeration in the range of 0°C to 10°C. This produce has a short shelf life and requires low-cost, small-capacity refrigeration units of 5 MT for preserving produce at the farm-gate level. Off-grid solar refrigerators can decrease spoilage losses, avoid distress sales, and improve income for farmers. States such as Uttar Pradesh, West Bengal and Madhya Pradesh alone require 1.9 million MT of installed capacity of refrigerators for the preservation of highly perishable fruits and vegetables (between 0^{0}C to 10^{0}C). Owing to an increased demand in this sector, the segmented market size of farm-gate refrigerators is estimated to be USD 3.7 billion, with an adoption rate of around 25%.

Lease/rent models and community owned models are the most favourable business models for off-grid solar refrigeration systems. In the lease/rent model and community owned business models the ownership lies with the companies and Farmer Producer Organisations (FPOs), respectively. The lease/rent model is preferred by small holder farmers and small processing industries as it does not involve high upfront capital investments. The lease or rent charges are flexible based on the type and quantity of produce and geographical location. In the community-based business model, the FPO manages the facility and charges each farmer for storage based on type, quantity, and time period. This model has been termed 'Cooling-as-a-Service' or CaaS. The CaaS business model potentially provides a huge opportunity for companies. The upfront purchase business model is preferred by cooperative societies as they retain ownership. It is, however, not viable for small holder farmers due to the high capital expenditure requirement. The key challenges hampering market development are the low purchasing power of farmers, poor access to formal sources of financing for newer technologies, and a lack of off-grid solar refrigerators with temperature variability. To support infrastructure development in the agriculture sector, the government has implemented various financial assistance schemes namely 'Mission on Integrated Development of Horticulture (MIDH)', 'Operation Greens' and 'Agriculture Infrastructure Fund'.

[17] Area and Production of Horticulture Crops 3rd Advance Estimate; Ministry of Agriculture and Family Welfare (Link)
[18] Press Release on Cold Storage Facilities in the Country for Storing Perishable Horticulture Produce; GoI; Sep 2020 (Link)
[19] Web Article - India wastes up to 16% of its agricultural produce; fruits, vegetables squandered the most; Financial Express; July 2019 (Link)

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Dairy (Milk)

In the dairy segment, the total addressable market for off-grid solar refrigeration is USD 164 million. India is the largest milk producing country in the world (~21% of global market share) with substantial requirements for on-site refrigeration. In 2018-19, the total milk production in the country amounted to 187 million tonnes.[20] The majority of dairy farmers use milk chillers to cool the milk from its harvest temperature of 35°C to 4°C, and arrest bacterial growth to maintain the quality. This avoids deterioration and allows milk to be used up to seven days. However, the milk cooling capacity of chilling centres and bulk milk chillers in India is only 0.060 million tonnes per day, while the average milk production is 0.51 million tonnes per day. On average, dairy farmers produce 30 litres of milk per day and require a cooling facility at the source to avoid bacterial growth. Additionally, at least 3% (15.4 million litres per day) of the total milk being produced in rural areas gets wasted due to unreliable and erratic electricity supply. To provide refrigeration, dairy farmers have to depend on diesel generators, which makes cooling expensive. Hence, off-grid solar milk chillers have a huge potential market in rural areas. In groups of 15, dairy farmers can purchase 500-litres of off-grid solar milk chilling capacity, which would be an optimal size for on-site refrigeration. Andhra Pradesh, Uttar Pradesh and Madhya Pradesh are among the top milk producing states in India with low volumes of milk chilling capacity.[21] These high potential states can be targeted for piloting of off-grid solar milk chillers. The segmented addressable market is USD 16 million with an early technology adoption rate of 10%.

The lease or rental model is the most promising business model for off-grid solar milk chillers, as the majority of the dairy farmers may not have the ability to purchase the chillers due to high upfront costs. Promethean Energy operates on a build-own-transfer (BOT) model. It creates assets of milk chillers with support from Non-Banking Financial Corporations (NBFCs) and provides this to customers on a rental basis.[22] This model enables risk sharing, which balances the payment and technology risks for the company and the customer. Cooling-as-a-service (CaaS) is also an emerging business model, where large private dairies provide CaaS to other milk collection centres during periods with comparatively low demand. For instance, Chitale Dairy in Maharashtra helps village level milk societies to chill milk using their own refrigeration units.[23] However, a lack of awareness about the benefits of off-grid solar refrigeration, limited options for financing and a lack of demonstrated bankable business cases reduces the adoption of off-grid solar milk chillers in rural areas. In this context, the government is providing incentives to cooperative societies in the organised dairy sector to install off-grid solar milk chillers at the source. The key government initiatives aimed at cold chain infrastructure development in the dairy sector are 'Animal Husbandry Infrastructure Development Fund (AHIDF)', 'Integrated Cold Chain and Value Addition Infrastructure Scheme' and 'Dairy Entrepreneurship Development Scheme (DDES)'.

[20] Basic Animal Husbandry Statistics 2019; Ministry of Fisheries, Animal Husbandry, and Dairying; GoI (Link)
[21] Ibid
[22] Web Article - Promethean's Rapid Milk Chiller (Link)
[23] Website – About Chitale Dairy (Link)

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Prevalent Off-Grid Solar Refrigeration Technologies in India

Solar powered applications can provide a reliable source of energy at a lower cost compared to diesel powered systems in weak-grid and off-grid areas.

Solar PV with PCM is the most viable technology for consumers considering its cost-economics in comparison to other solar-powered refrigerators.

	100-litre capacity	150-litre capacity	268-litre capacity	5 MT capacity	500-litre capacity
Solar PV with PCM Thermal Battery	TCO:USD 5,930 OPEX: USD 9/Litre CAPEX: USD 50/Litre	TCO:USD 1,130 OPEX: USD 2/Litre CAPEX: USD 6/Litre	TCO:USD 1,467 OPEX: USD 1.5/Litre CAPEX: USD 4/Litre	TCO:USD 39,070 OPEX: USD 4,000/MT CAPEX: USD 3,800/MT	TCO:USD 6,130 OPEX: USD 0.8/Litre CAPEX: USD 6/Litre
Solar PV with Battery	TCO:USD 6,100 OPEX: USD 16/Litre CAPEX: USD 4.5/Litre	TCO:USD 1,225 OPEX: USD 1/Litre CAPEX: USD 7/Litre	TCO:USD 1,492 OPEX: USD 2/Litre CAPEX: USD 4/Litre	TCO:USD 44,330 OPEX: USD 4,200/MT CAPEX: USD 4,600/MT	TCO:USD 6,670 OPEX: USD 2/Litre CAPEX: USD 11/Litre
Solar PV with Biomass				TCO:USD 47,200 OPEX: USD 4,000/MT CAPEX: USD 5,400/MT	
Solar PV with Battery and Grid		TCO:USD 1,143 OPEX: USD 2/Litre CAPEX: USD 5/Litre	TCO:USD 1,846 OPEX: USD 4/Litre CAPEX: USD 3/Litre		
Solar PV with Battery on Grid and Diesel Generator				TCO:USD 59,800 OPEX: USD 9,200/MT CAPEX: USD 2,700/MT	
Refrigerator on Diesel Generator	TCO:USD 7,040 OPEX: USD 37/Litre CAPEX: USD 433/Litre	TCO:USD 1,894 OPEX: USD 12/Litre CAPEX: USD 1/Litre	TCO:USD 2,998 OPEX: USD 10/Litre CAPEX: USD 1/Litre	TCO:USD 145,163 OPEX: USD 27,100/MT CAPEX: USD 1,900/MT	TCO:USD 29,520 OPEX: USD 52/Litre CAPEX: USD 7/Litre

Ecosystem of Off-Grid Solar Refrigeration System in India

This study has identified the existing ecosystem support options (in terms of policy, development programs and financing) that influence market development for off-grid solar refrigerators. The key ecosystem players are policy makers (national level ministries and nodal implementation agencies), development actors (such as donor agencies and private foundations) and financiers (commercial financial institutions, impact investors and venture capitalists). These players, through the provision of technical and financial assistance, can facilitate the development of innovative technologies and steer market growth in the off-grid solar refrigeration sector.

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Existing Policy Framework in India

In India, the government has a limited number of schemes that promote off-grid solar refrigerators as part of larger programmes. The majority of the schemes implemented by the government at the national and state level give incentives to large scale cold chain infrastructure development, specifically in the agriculture, dairy and healthcare sectors. In these sectors, the interventions adopted by the government include either guidelines or financial assistance through capital subsidies, interest subventions, and concessional loans. Some of the most relevant schemes of the government pertaining to refrigeration are provided in Table 1.

Table 1: Relevant policies and schemes for off-grid solar refrigeration

Ministry	Scheme	Financial Outlay
Ministry of New and Renewable Energy (MNRE)	Scale up of Access to Clean Energy for Rural Productive Use[24]	Total project cost of USD 23.04 million 2018-2020)
Ministry of Agriculture and Farmers Welfare (MoAFW)	Mission on Integrated Development of Horticulture (MIDH)[25]	Budget of USD 244 million (2020-21) for the National Horticulture Mission (NHM) and Horticulture Mission for North East and Himalayan States (HMNEH) sub-schemes[26]
	Agriculture Infrastructure Fund[27]	Budget of USD 1.3 billion (2020-21)
Ministry of Food Processing Industries (MoFPI)	Integrated Cold Chain and Value Addition Infrastructure[28]	Estimated budget[29] of USD 46.53 million (2020-21)
Ministry of Fisheries, Animal Husbandry and Dairying (MoFAHD)	Animal Husbandry Infrastructure Development Fund (AHIDF)[30]	Budget outlay of USD 2 billion (2020-21 and 2022-23)
	Dairy Entrepreneurship Development Scheme[31]	Budget outlay[32] of USD 43.33 million (2019-20)

[24] Website - Schemes of Ministry of New and Renewable Energy (Link)
[25] Mission for Integrated Development of Horticulture: Operational Guidelines (Link)
[26] Administrative Approval for the MIDH Scheme in 2020-21, Ministry of Agriculture and Farmers Welfare (Link)
[27] Press Release on Agriculture Infrastructure Fund by the Prime Ministers' Office (Link)
[28] Scheme for Integrated Cold Chain and Value Addition Infrastructure: Operational Guidelines; Ministry of Food Processing Industry; December 2019 (Link)
[29] Detailed Demand for Grants 2020-21; Ministry of Food Processing Industry (Link)
[30] Pres Release on Approval of Animal Husbandry Infrastructure Development Fund; June 2020 (Link)
[31] Brochure for Dairy Entrepreneurship Development Scheme (Link)
[32] Website - Dairy Entrepreneurship Development Scheme 2019-20; National Bank for Agriculture and Rural Development (Link)

Executive Summary

Development Support Programs on Innovations

In recent years, the off-grid solar refrigeration sector has gained momentum due to focused interventions by development partners. Through program interventions, development partners are providing technical assistance to governments for policy design and implementation in the off-grid solar sector. They are also supporting enterprises in raising funds through challenge/innovation funds, and assisting enterprises in business and financial planning via incubation programs. Some of the programs targeting development in this sector are as follows:

Table 2: Select development support programs supporting off-grid solar refrigeration in India

Funder	Program Name	Duration	Value
International Finance Corporation (IFC)	Lighting Asia	2012-ongoing	n/a
Global Environment Facility (GEF)	Facility for Low Carbon Technology Deployment (FLCTD)	2015-2020	USD 68.5 million
Foreign, Commonwealth and Development Office (FCDO)/Shell Foundation	Transforming Inclusive Energy Markets (TIME)	2016-2021	USD 78 million
Foreign, Commonwealth and Development Office (FCDO)	Low-Energy Inclusive Appliances (LEIA)	2017-2022	USD 24 million
United Nations Development Program (UNDP)/ GAVI alliance	Electronic Vaccine Intelligence Network (eVIN)	2017-2022	USD 29 million
UK Aid/IKEA Foundation	Efficiency for Access Research and Development Fund	2019	USD 2.23 million (grant to 13 companies)

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Executive Summary

Financing Options for Off-Grid Solar Refrigeration Systems

Companies in the off-grid solar sector have options to access debt and equity financing through impact investors/venture capitalists and funds targeting decentralised renewable energy applications. Some of the key investors in this segment are Acumen, Sangam Ventures, Sathguru Catalyser, Omnivore, and Caspian, among others. In 2017, Acumen Fund, a social venture capital investor, launched the USD 20 million 'Pioneer Energy Investment Initiative' (PEII). As of 2019, Caspian, a social impact investment firm, has invested USD 17 million in the affordable and clean energy sector.[33] Sangam Ventures, an early-stage venture fund, provided equity funding of USD 0.25 million to Inficold for setting up solar powered refrigerators in 2018.[34] One of the recent funds raised to support the clean energy sector is a USD 5 million fund by cKers finance. This was to catalyse growth of distributed solar energy, including solar refrigerators.[35] In 2019, the Nabventures Fund I was announced by NABARD with a corpus of USD 66.67 million and a green-shoe option of USD 26.67 million for equity investments in food, agriculture, and rural start-ups.[36] These ecosystem financiers are providing commercial investment to early-stage enterprises, thereby supporting innovation in the off-grid solar refrigeration sector.

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[33] Caspian Impact Investments Social Performance Report 2018-19; Caspian (Link)
[34] Web Article -From Cooling Tech for Intel to Chilling Milk Even Without Electricity, The Journey Of Inficold Founders; Economics Times; Oct 2018 (Link)
[35] Web Article - Distributed solar lender cKers Finance raises $5 million from US investor New Energy Nexus; Pv Magazine; March 2020 (Link)
[36] Web Article - Nabventures Launches Maiden Fund to Back Agri, Food and Rural Start-Ups; Economic Times; May 2019 (Link)

Executive Summary

Impact of Off-Grid Solar Refrigeration Systems in India

This study finds that the implementation of off-grid solar refrigerators can provide dual benefits to the economy. It can achieve SDG targets and create value for society. Off-grid solar refrigeration impacts seven SDGs directly (SDG 1, 2, 3, 5, 7, 8, and 13). Some of the impacts of off-grid solar refrigeration on consumers, industries, environment, and economy are highlighted below:

Impact on Consumers: The implementation of off-grid solar refrigerators at the farm-gate can improve the livelihoods (SDG 1 – poverty reduction) of small holder farmers. It can reduce post-harvest loss of highly perishable crops and increase their profits. For households, off-grid solar refrigerators contribute to improved food security (SDG 2 – zero hunger) by supporting reductions in food waste and losses. It also impacts SDG 3 (good health and well-being), as customers benefit from the increased variety in diets. Off-grid solar refrigerators can also be an important contributor to greater gender equality (SDG 5) as they reduce time poverty for women. In the health sector, off-grid solar vaccine storage enables vaccine distribution and storage in remote areas, which contributes to SDG 3.

Impact on Business: The availability of cooling facilities at rural micro-enterprises impacts socio-economic growth positively. It increases purchasing power, contributing to SDG 1 and SDG 8 (entrepreneurship). A recent pilot study found that micro-enterprises using off-grid solar refrigerators increased profits by USD 57 per month in India.[37] Off-grid solar refrigeration can also create new livelihood opportunities, particularly for women to set-up home-based enterprises for selling perishable goods (such as vegetables, cooked food, fruits, fish etc.). This helps to achieve SDG 5 and SDG 8.

Impact on Environment: Off-grid solar refrigeration for reefer vehicles and refrigerators-on-wheels can reduce air pollution levels and contribute to SDG 7 (clean energy) and SDG 13 (climate action). According to the Food Agriculture Organisation (FAO)," every wasted tonne of fruits and vegetables results into approximately 1.1 CO2eq. emissions in the South Asia region".[38] As such, off-grid solar refrigeration reduces greenhouse gas emissions by preserving food produce and saving water, thereby supporting SDG 13. Further, energy efficient appliances can lead to energy savings and reduce pollution.

Impact on Economy: Off-grid solar refrigeration support progress toward SDG 1 by increasing incomes of people who are economically disadvantaged. By creating demand for energy services, it supports job creation in rural areas. Off-grid solar refrigeration plays an incremental role in driving demand for energy and supporting the achievement of universal energy access by 2030 (SDG 7).

[37] Use Cases and Cost Breakdown of Off-Grid Refrigeration Systems; Efficiency for Access Coalition; May 2020 (Link)
[38] The State of Food and Agriculture 2019. Moving Forward on Food Loss and Waste Reduction; FAO; 2019 (Link)

Executive Summary

Key Recommendations for the Off Grid Solar Refrigeration Market Ecosystem

The study has emphasised the need for creating an enabling policy, market and financial ecosystem with targeted interventions for off-grid solar refrigeration. The proposed recommendations have been identified to address certain challenges such as a low awareness of these technologies among consumers and financiers, the limited regulatory push, and the high upfront capital costs of off-grid solar refrigeration technology. It also addresses the lack of information on consumer market segments, and limited consumer and company financing options. These recommendations are complementary and yet, address specific challenges. This study suggests implementing these recommendations simultaneously to create an enabling landscape for market development of off-grid solar appliances. The keys to achieving market potential are making improvements to product affordability through consumer financing and economies of scale, increasing consumer awareness through marketing, improving access to finance for companies to develop innovative technologies, and gathering deeper consumer insights.[39] The table below gives an overview of recommendations for different actors.

Table 3: Key recommendations for promotion of off-grid solar refrigeration sector

Actor	Key Recommendations
Government	• Design targeted policies for off-grid solar refrigeration at the national level to achieve access to energy targets aligned with SDG 7 • Promote awareness on existing product testing methods and performance metrics for off-grid solar refrigerator technologies to improve consumers' and financial institutions' confidence on product reliability • Rationalise existing tariffs on solar components and provide tax incentives to companies manufacturing off-grid solar refrigerators to reduce capital costs • Create a national level fund targeted to support the manufacturing of off-grid solar refrigerators with a specific provision of financial assistance to companies
Donor agencies and financial institutions	• Design innovative financial instruments like blended finance for supporting emerging and innovative business cases • Explore consumer financing options like revolving funds or viability gap funding to improve affordability of off-grid solar refrigerators • Fund R&D and pilots
Companies	• Provide advisory support to consumers across the value chain as an attractive package of services • Develop and demonstrate bankable projects and proof-of-concept to avail commercial financing • Implement innovative business models that reduce upfront capital investment equirements (pay-as-you-use) to improve the affordability of off-grid solar refrigerators • Generate consumer awareness on the benefits of the technology and availability of schemes to support market expansion
Other ecosystem players (i.e., associations/ foundation/ NGOs etc.)	• Establish a digital platform with data on technology applications and potential market segments to enhance knowledge about off-grid solar refrigerators • Design and implement a training program on financing of off-grid solar productive appliances for financial institutions in rural areas • Demand aggregation of off-grid solar refrigerators to achieve economies of scale and reduce unit price of the product for consumers

[39] Webinar: State of the Off-grid Appliance Market 2019; Efficiency for Access Coalition; 2019 (Link)

1 Introduction

1.1 Context Of The Study

The United Nations Sustainable Development Goal (SDG) 7 highlights the need for equitable access to affordable, reliable, and sustainable energy. The World Bank states that there is strengthening link between socio-economic benefits and access to affordable and sustainable energy.[40] However, many people across the world still lack access to 24x7 grid electricity supply. Globally, there are more than two billion households that are dependent on alternative solutions to meet their energy demands.[41] In addition to households, alternative energy solutions are required for businesses, which may not be grid-connected. As a result, the off-grid solar sector is currently leveraged by over 420 million users to access energy services.[42]

In India, the reliability of grid-based electricity remains a challenge, despite an electrification rate of 99.93% (as per the Saubhagya Dashboard).[43] This estimate includes provisions like power packs for lighting and mobile charging in households across rural areas. The Electricity Supply Monitoring Initiative (ESMI) data shows that rural areas in several states face frequent power cuts and voltage fluctuations on a daily basis. For example, in January 2019, the rural areas monitored in Uttar Pradesh had no electricity supply for 9 hours and low voltage for 2 hours on average per day.[44] Overall, 48% of the ESMI locations (65 rural and 126 urban areas) lacked electricity supply for more than 15 hours in January 2019.[45] These voltage fluctuations and unreliable grid connections can damage or limit the use of appliances by households and micro-enterprises. Therefore, there is a market opportunity for productive-use customers in rural areas who require predictable and consistent electricity supply to supplement grid access. This can be addressed by off-grid solar appliances such as refrigerators, water pumps, dryers etc. Furthermore, the demand for electricity is expected to triple between 2018 and 2040 in India. This is largely for meeting cooling requirements and increasing appliance ownership.[46] Accelerated efforts are required to address the basic energy needs of off-grid and weak-grid households and small businesses in India.

Off-grid solar appliances can play a transformative role in improving people's health and socio-economic status. By unlocking latent demand for energy services, off-grid appliances (such as televisions, fans, and refrigerators) have the potential to deliver significant economic, health, education, and other benefits for a large number of rural customers. They contribute to achieving SDG 1 (poverty reduction), SDG 2 (food security), SDG 3 (health and well-being), SDG 4 (education), SDG 7 (clean energy), SDG 8 (jobs and entrepreneurship) and SDG 13 (climate action).[47] There is an increasing need to focus on providing energy efficient appliances for productive uses in rural areas in India. One of the potentially beneficial productive use-cases is refrigeration, which contributes to SDG 1, 2, 3, and 8 directly.

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[40] Sustainable Development Goal on Energy (SDG7) and the World Bank Group; The World Bank; May 2016 (Link)
[41] The State of the Off-grid Appliance Market; Energy for Access Coalition, UKAID; October 2019 (Link)
[42] Off-grid Solar Market Trends Report 2020 – Executive Summary; GOGLA; February 2020 (Link)
[43] Saubhagya Dashboard; GoI (Link)
[44] Electricity Supply Monitoring Initiative Dashboard; Prayas Energy (Link)
[45] Analysis Reports: ESMI Dashboard; Prayas Energy (Link)
[46] India 2020: Energy Policy Review; International Energy Agency; Jan 2020 (Link)
[47] The State of the Off-grid Appliance Market; Energy for Access Coalition, UKAID; October 2019 (Link)

1 Introduction

1.1 Context Of The Study

The off-grid refrigeration industry is still nascent. In India, by the first half of 2020, only 153 units were reportedly sold (~11% of global share) to micro-enterprises and households.[48] The key market barrier is the availability of products that match the needs and financial abilities of rural customers. There is potential for low-cost energy efficient DC refrigerators to fill the market gap in weak-grid and off-grid rural areas. Conventional AC refrigerators require a continuous supply of power, which makes them unreliable for use with intermittent grid connections, especially in the case of cold chain infrastructure and vaccines that require strict temperature control. For example, the three-star rated energy-efficient AC refrigerators (rated by Bureau of Energy Efficiency) consume around 311 kWh of electricity annually.[49] This creates an opportunity for efficient DC refrigerators. However, in order to be viable in off-grid settings and suitable for rural customers, refrigerators must become considerably cheaper, and run on far less energy than most conventional products.

In this context, GOGLA engaged Intellecap to map the potential for off-grid refrigeration technology in India. To support market development for off-grid solar appliances, GOGLA along with its partners, has initiated market intelligence studies as a part of the Low-Energy Inclusive Appliances (LEIA) program in India. Recent studies suggest a growth in consumer demand for off-grid refrigeration in the household, commercial, and agricultural sectors. This has the potential to drive significant economic growth. The provision of efficient refrigerators to household users and micro-enterprises can support reduction in food wastage, improve food security, reduce food-related illness as well as contribute to income generation activities. However, at present, the off-grid refrigeration market remains untapped in India. This is mainly due to the high upfront costs, poor consumer awareness on the availability and benefits of the technology, limited understanding on how to handle perishable agricultural and dairy produce, and a lack of market information. Hence, there is a need to promote low-cost, high-quality, energy-efficient refrigerators customised for weak-grid and off-grid rural areas in India.

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[48] Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data (Jan-July 2020); GOGLA; 2020 (Link)
[49] Web Article - Updated Star Rating by BEE; Down to Earth; Sep 2018 (Link)

1 Introduction

1.2 Study Objective

The objective of this report is to generate evidence-based information on the potential of off-grid solar refrigeration for companies, policy makers/influencers and development partners.

This study aims to provide information on the following aspects:

- Existing scenarios (technology and applications) for off-grid solar refrigerators for households, micro-enterprises and smallholder farmers
- Market segmentation based on a needs assessment
- Market potential for off-grid solar refrigeration across key segments
- Market dynamics (barriers and opportunities)
- Cost economics of different types of technology
- Innovative business models and consumer financing options to improve last mile access
- Profiles of active players in the market

1.3 Relevant Market Segments

This report captures information across five key market segments which include healthcare (vaccines), households, micro-enterprises, dairy (milk), and farm-gate (fruits and vegetables). These five market segments offer an immediate opportunity for introducing off-grid solar refrigeration in weak-grid and off-grid areas, considering the need for reliable energy supply for productive use. For all five of these market segments a needs assessment was undertaken based on primary and secondary research. The research finds that the existing market for off-grid solar refrigeration is nascent and fragmented across all five market segments. However, there exists strong potential for growth.

In the healthcare segment, off-grid solar refrigerators can prevent wastage of vaccines arising due to temperature fluctuations. Across rural India, around 50% of the primary health centres (PHCs) do not have continuous electricity supply.[50] Several healthcare products (such as vaccines, biopharmaceuticals, blood etc.) are temperature sensitive and need to be stored at temperatures ranging from -20°C to +20°C. Further, it is estimated that 25% of vaccines are wasted due to improper cooling and poor supplychain management; especially in rural areas.[51] Vaccines require controlled temperatures ranging from 2°C to 8°C[52], which is difficult to maintain in the absence of continuous electricity supply. The ongoing pandemic (COVID-19) has intensified the need for upgrading the country's healthcare cold chain infrastructure. In this context, the government is also driving a significant push for the proper storage of vaccines under the ambit of the "Universal Immunization Program" and "National Vaccine Policy". Overall, there exists a huge market for solar vaccine storage in PHCs, sub-health centres (SHCs), ambulances and chemists in weak-grid and off-grid rural areas.

Residential households in off-grid and weak-grid areas need refrigeration to address food storage issues. Around 40% of the rural households (from a sample of 10,049 households across four major states of Bihar, Uttar Pradesh, Rajasthan, and Odisha) do not receive 24x7 adequate and reliable grid electricity supply.[53] Unreliable electricity supply with long power shortages impacts the reliability of AC refrigerators in rural areas. Many households in India are able to use standard AC refrigerators for only 2–4 hours a day in off-grid or weak-grid areas with intermittent grid supply.[54] Irregular refrigeration can lead to food spoilage. The availability of affordable off-grid solar refrigerators can help improve food security and reduce nutrition related illnesses in rural areas.

[50] The State of Electricity Access for Primary Health Centres in India; Council on Energy, Environment and Water (CEEW); February 2019 (Link)
[51] Vaccine Wastage Assessment: Field Assessment and Observations from National stores and Five Selected States of India; UNICEF; 2010 (Link)
[52] Vaccine Storage and Handling; Pan American Health Organisation (Link)
[53] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[54] The State of the Global off-Grid appliance Market; Dalberg for Global LEAP; 2016 (Link)

1 Introduction

1.3 Relevant Market Segments

Micro-Enterprises in rural areas, especially retails shops can expand product offerings with off-grid solar refrigerators. In recent years, there has been a noticeable increase in demand for chilled beverages and products in rural areas. This reflects the changing consumer preference. Refrigeration can help micro-enterprises earn a premium on chilled products, especially during summer months. A recent pilot study in India found that micro-enterprises using off-grid solar refrigerators increased profits by USD 57 per month.[55] Considering, only 65% micro-enterprises (from a sample of 2,019 across 200 villages in the four states of Uttar Pradesh, Bihar, Rajasthan and Odisha) in rural areas are connected to the electric grid, off-grid solar refrigeration can have a substantial market share in this segment.[56]

Off-grid solar refrigeration presents significant economic opportunity in the farm-gate segment. Over the years, India has witnessed a marked increase in the consumption of perishable produce, especially fruits and vegetables. However, a lack of adequate refrigeration infrastructure results in the wastage of up to 16% of fruits and vegetables annually.[57] Farmers without access to refrigerators/cold storages often sell their produce at low prices to avoid spoilage. The estimated post-harvest losses of fruits and vegetables due to poor refrigeration facilities is USD 8.4 billion per annum in India.[58] The ability to store perishable produce at cooler temperatures can decrease spoilage losses, reduce distress sales, and help increase income for the farmers.

Off-grid solar milk chillers can propel income generation by increasing the shelf life of milk, and enhance sales volume in the dairy segment. India is the largest producer of milk in the world, therefore any loss in milk due to inadequate refrigeration and unreliable electricity can lead to significant economic losses.[59] Annually at least 3% of milk produced is wasted due to unreliable and erratic electricity supply in India.[60] Currently, dairy farmers depend on diesel generators, which make the refrigeration process expensive.[61] Milk can be used for seven days by avoiding deterioration and bacterial growth if it is cooled on the site of harvesting at the right temperature of 4°C. The demand for milk is projected to increase to 180 million tonnes by 2022, as a result of growing population, economic growth and higher health consciousness. This demand requires proper milk chilling facilities at the source.[62] Hence, there is strong potential for independent dairy farmers to form small dairy cooperative societies, or dairy farmer groups in rural areas to adopt appropriately priced off-grid solar milk chillers.

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[55] Use Cases and Cost Breakdown of Off-Grid Refrigeration Systems; Efficiency for Access Coalition; May 2020 (Link)
[56] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[57] Saving the Harvest: Reducing the Food Loss and Waste. Policy Brief No. 5; National Academy of Agricultural Sciences; May 2019 (Link)
[58] Web Article - Poor post-harvest storage, transportation facilities to cost farmers dearly; Down To Earth; August 2018 (Link)
[59] Cooling Solutions for Cold Chains; SE4All; March 2018 (Link)
[60] Web Article - Solar cold storage and other solutions preventing milk wastage in India; Financial Express; November 2019 (Link)
[61] Ibid
[62] Web Article - India: Increasing demand challenges the dairy sector; FAO (Link)

2 Research Methodology

Intellecap adopted a three-pronged approach for this study which comprises of literature review, consultations with key ecosystem players, and market estimation and cost modelling. The insights were generated using a mixed methods approach incorporating qualitative and quantitative data collected during the research. The detailed methodology and analytical process is explained below.

2.1 Literature Review and Primary Research

A literature review was undertaken to assess the existing landscape of off-grid solar refrigerators in India. This included capturing information on the need for off-grid solar refrigerators, types of technology, viable market segments, business and financial models, ongoing policy and programmatic initiatives, and the barriers/challenges impacting growth of the sector. The team collated qualitative and quantitative data on critical aspects related to the technology (such as size, capital cost, operating expenses, and energy usage) to assess the market potential and calculate the total cost of ownership of off-grid solar refrigerators. Key geographies with high potential for pilot demonstrations were also analysed for each market segment. The main sources of information/data consisted of (a) research and market studies on the off-grid solar refrigeration sector; (b) databases by the government, development partners and non-governmental organisations (e.g. Social and Economic Caste Census 2011, Census 2011, National Family Health Survey 2015-16, Agriculture and Dairy Production Statistics 2018-19 etc.); (c) published reports and brochures by companies; (d) policy guidelines by the government and program information/appraisal documents by donor agencies; and (e) websites/blogs of stakeholders including companies, development partners and financial institutions. The list of references is given in Annexure A.

More than 40 stakeholders were interviewed to undertake a qualitative assessment. This was used to determine the market potential of off-grid solar refrigerators across different segments. Firstly, the team mapped all the relevant stakeholders into four key groups i.e. companies, development partners, financiers (i.e. financial institutions, impact investors, venture capitalists etc.), and other key stakeholders (relevant non-governmental organisations/think tanks/consumers) operating in the off-grid solar refrigerator sector. After mapping the relevant stakeholders, a key informant interview (KII) guide was prepared by the study team. The interviews were conducted via phone or online video/voice conference calls. The companies were selected based on the application of their technologies across the five market segments of healthcare (vaccines), households, micro-enterprises, dairy (milk), and farm-gate (fruits and vegetables). To support the market potential assessment, companies provided information on off-grid refrigeration technologies, existing market segments, business models, financing support, regulations/schemes, geographical dispersion, distribution channels, and challenges. This information was collated during the primary survey. The development partners were engaged to suggest the market landscape of off-grid solar refrigerators, existing and planned programs and strategies, funding landscape, and recommendations to create an enabling ecosystem. The financiers helped understand the existing financial products for different off-grid technologies, innovative financing mechanisms, barriers/challenges related to financing, and recommendations to aid company and consumer financing. The other stakeholders (NGOs/think tanks/consumers) were interviewed to explore the market drivers (demand and supply), barriers from consumer and ecosystem perspective, existing government policies and regulations and recommendations to create an enabling ecosystem. The list of stakeholders consulted is given in Annexure B. The information and data from the literature review and KIIs were triangulated to capture insights on the market potential of off-grid solar refrigerators across the five market segments. This also points to the critical barriers impeding the growth of the sector and opportunities for market development.

2 Research Methodology

2.2 Analytical Approach

2.2.1 Content Analysis

The qualitative data and information collected from this primary research has been analysed to generate insights across key thematic areas. The study team undertook an in-depth analysis of research/market study reports and over 40 KIIs to generate findings across common points of inquiry. The framework mapping the key thematic areas based on expected outcomes of discussion for each stakeholder group is given in Table 4. After mapping of these insights, the study team further disaggregated the findings based on the five market segments. This two-stage process of content analysis helped generate relevant findings across thematic areas for each market segment.

Table 4: Framework mapping the key thematic areas for each stakeholder group

Thematic Area	Stakeholder Group			
	Companies	Development Partners	Financiers	NGOs/Think Tanks/ Consumers
Technology application	●	●		●
Business models	●	●		●
Market drivers	●	●		●
Barriers/challenges	●		●	●
Financing mechanisms	●	●	●	●
Government policies	●	●	●	●
Opportunities	●	●	●	●

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2 Research Methodology

2.2.2 Market Sizing

The study team used a demand side approach for calculation of the targeted addressable market (TAM) and segmented addressable market (SAM) for the five segments. The step-by-step process followed for each market segment is defined below:

Definition of TAM and SAM[63]

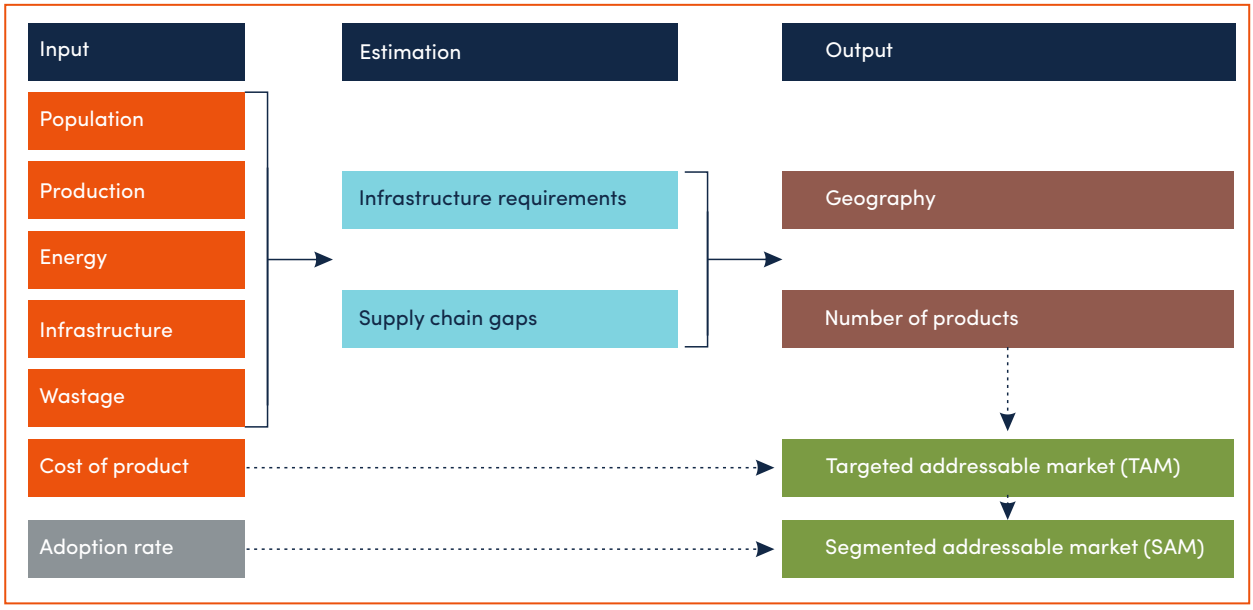
TAM is the total market demand for a particular product or service calculated from the potential customer base and availability of the product for the market segment.

SAM is a portion of TAM that can be immediately serviced by companies based on the rate of adoption for a specific market segment.

- Collate data on inputs which includes demand side variables (such as population, production, energy access, infrastructure, wastage and unit cost of the technology) and assumption on the adoption rate.
- Estimate the gap in the supply chain of solar refrigeration sector based on the inputs.
- Identify the potential geographical locations to derive the demand for off-grid solar refrigerators (i.e. number of opportunities) as per the demand-supply gap analysis.
- Calculate the total addressable market (TAM) by multiplying the cost of the product with the estimated demand for off-grid solar refrigerators.
- Calculate the segmented addressable market (SAM) based on the applicable adoption rate of technology for each market segment.

The general schematic of the market sizing process is given in Figure 3. The detailed calculations and specific assumptions as per market segments are described in Chapter 3.

Figure 3: Process of calculating the market size



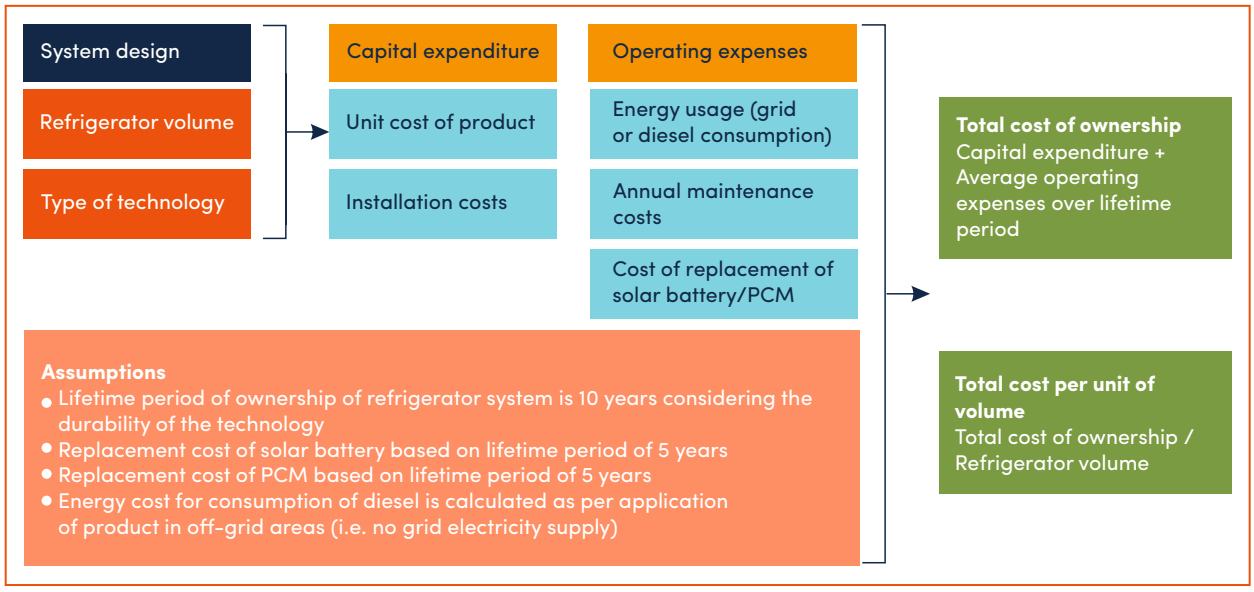
[63] Note: Definition adapted from multiple secondary sources

2 Research Methodology

2.2.3 Cost Modelling

The cost model used for off-grid solar refrigerators estimates the total cost of ownership with respect to upfront capital expenditure and operating expenses for each market segment over a lifetime period of 10 years. The approach provides cost estimates considering the durability and performance of the various components such as the refrigerator, solar panel, and battery. Capital expenditure consists of unit price of the off-grid solar refrigerator and installation cost, while the operating expenditure includes costs pertaining to energy usage, maintenance and replacement of battery/phase change material technology. The cost model allows for comparison over the different cost components of an off-grid solar refrigerator based on type of technology for a consistent size of the product. The ideal size of the product and price is based on the existing consumer demand for each market segment as per discussions with companies during primary research. The model also includes the cost comparison between off-grid solar refrigerators and refrigerators running on diesel generators. This comparative analysis highlights the most cost-effective technology applicable for each market segment. The breakdown of costs can be useful for the companies to identify prospective cost reduction strategies. A general schematic of the model applied in this study is given in Figure 4. It highlights the variables and assumptions used for estimation of the total cost of ownership. The data points for each of these variables are based on primary or secondary research. It is important to note that the given model does not include all parameters affecting the viability of off-grid solar refrigerators. The cost model uses simple costs for estimation of the TCO and does not consider levelised costs. Future costs (such as maintenance, fuel, replacement parts) have not been discounted to the present with a discount factor. The TCO calculation for refrigerators with diesel generators does not consider the capital cost or maintenance cost of the diesel generator. All costs pertaining to the diesel generator would be distributed to all the products that may use diesel generators (i.e. lights, fans, refrigerator, other machines, etc. across household, micro-enterprise, healthcare centre, agri-business centre or milk processing centre). It is difficult to attribute these costs specifically to the refrigeration unit. The aim is to examine the variability of energy costs for application of refrigerators with either solar-based technology, or grid connection and diesel generators.

Figure 4: Schematic diagram of the cost model



3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

The key market segments that have been considered for assessing the market potential are healthcare (vaccines), households, micro-enterprises, dairy (milk), and farm-gate (fruits and vegetables). For the purpose of this study, the defined market segments offer an immediate opportunity for introducing off-grid solar refrigeration in weak-grid and off-grid areas. The figure below illustrates key market dynamics relating to each market segment.

Figure 5: Snapshot of the market dynamics in five key market segments

Vaccine
- Market potential for refrigeration of vaccines at healthcare sector and chemists (for last mile delivery) as a result of COVID-19
- A time consuming and complicated tendering process discourages companies from applying
- Government is the largest buyer of vaccine storage for supply at PHCs and other institutions

Household
- Increasing demand for refrigerators from rural areas due to improved income and standards of living
- High upfront cost of technology and lack of consumer financing limits uptake by households
- NGOs/Foundations provide financial support to households for purchase of solar refrigerators

Micro-Enterprises
- Potential demand from shop owners to maintain perishable items (cold drink, cold water, ice cream, etc.)
- High upfront costs of technology and poor access to commercial finance are key challenges
- Along with retail sales, companies prefer partnership with large corporates for bulk sales

Farm-Gate
- Recent policies support the farm-gate off-grid refrigerator sector
- Majority of the cold storage supports single commodity - usually the potato; there is a need for multi-commodity storage
- To improve access for small holder farmers, lease/rent model has been piloted by few companies

Dairy
- Increasing year-on-year milk processing requires an improved chilling capacity
- Highly unorganized sector; majority of the farmers sell milk to local milk collectors
- Direct sales of milk chilling units exist only for large federations and societies

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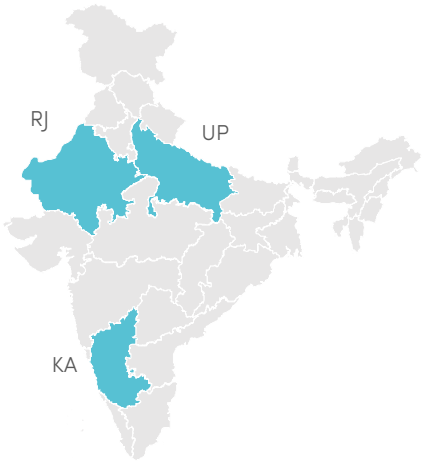
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1 Healthcare (Vaccines)

3.1.1 Market Size and Need Assessment

The total addressable market (TAM) for off-grid solar vaccine refrigeration is estimated to be around USD 811 million in weak-grid and off-grid rural areas.[64] With the ongoing pandemic (COVID-19), it has become necessary for the government to upgrade the healthcare cold chain/storage infrastructure to reduce the wastage of the vaccines, especially in rural areas. Aligned with the government's strategy on improving supply chain management in the healthcare sector, this report considers vaccine refrigeration as a potential market sub-segment for off-grid solar refrigeration. In rural India, primary healthcare is provided through a network of Sub-Health Centres (SHCs) and Primary Health Centres (PHCs). In 2014-15, the total number of SHCs and PHCs were 153,655 and 25,308 respectively.[65] Of the total PHCs, 45% of the PHCs were concentrated in the states of Uttar Pradesh (3,497), Karnataka (2,353), Rajasthan (2,083), Bihar (1,883) and Maharashtra (1,881).[66] Currently, there is a shortage of around 8,254 PHCs in India (as per Government of India norms that suggests availability of one PHC for every 30,000 citizens[67]). The inadequate PHCs is a major challenge for India's public healthcare system, as they are the first point of contact between a patient and healthcare workers in the rural areas. The segmented addressable market for off-grid solar vaccine storage is estimated at USD 81 million; as per Roger's bell curve analysis, the early adoption rate of technology is 10%.[68]

Figure 6: Potential states for off-grid solar vaccine storage



Lack of reliable electricity supply further accentuates the problem. The availability of electricity in healthcare facilities is a critical determinant of the efficacy of health service delivery. It is required to ensure proper functioning of medical equipment for patient care and enable refrigeration of supplies (including vaccines) and biological samples. In the absence of regular electricity access in the PHCs, on-site backup generation through diesel systems is necessary for the 24X7 availability of all healthcare services. The use of diesel generators has a detrimental impact on the environment and health, as it contributes to air pollution. Overall, 41% of the PHCs have an irregular supply of electricity and 9% of the PHCs do not have any electricity connection in India.[69] Power cuts are a major challenge in rural areas, with 20% of PHCs suffering from regular power cuts and an additional 2% facing power cut during summer i.e. April to June. More than 80% of the PHCs in the states of Uttar Pradesh and Karnataka face challenges in health service delivery due to irregular electricity supply or no grid connection.

[64] Note: Intellecap Analysis
[65] Rural Health Statistics 2014-15; Ministry of Health and Family Welfare; GoI (Link)
[66] Note: The data on number of PHCS has been taken for 2014-15 to ensure consistency with the analysis of electricity availability in PHCs. The analysis on availability of electricity is based on baseline data of 2012-13 (as per the DHLS-IV survey).
[67] Indian Public Health Standards (IPHS) Guidelines for Primary Health Centres; GoI; 2012 (Link)
[68] Note: The Roger's Bell Curve analysis classifies users for the adoption or acceptance of a new product or innovation into various categories, based on their willingness to accept new technology or an idea
[69] The State of Electricity Access for Primary Health Centres in India; CEEW; February 2019 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1.1 Market Size and Need Assessment

The states of Karnataka, Rajasthan and Uttar Pradesh have the greatest potential to install off-grid solar vaccine storage at a pilot stage. These are the states that have the maximum number of PHCs as well as a high proportion of PHCs with unreliable electricity supply. These states have been selected based on a ranking of all states across two parameters. These include (i) number of PHCs and (ii) states with highest percentage of PHCs with irregular or no electricity supply. Furthermore, these states can be considered for off-grid solar vaccine storage market entry due to ongoing activities by donor agencies and the government's 'Universal Immunization Program' and 'Electronic Vaccine Intelligence Network (eVIN) Program'.

By providing a reliable electricity supply, off-grid solar refrigeration can ensure that vaccines are stored properly, and at the requisite temperature. In general, vaccines are sensitive to heat and light, while some are also sensitive to freezing. Vaccines require a controlled temperature range from 2°C to 8°C.[70] To be effective, a vaccine must be safe and have the requisite potency. Vaccines can lose their potency if proper storage and transportation at an appropriate temperature and condition are not possible. Due to these issues, 25% of vaccines in India are wasted annually.[71] Thus, it is important to provide efficient refrigeration/cold chain infrastructure. However, over one-third of the PHCs do not have fully functional cold chain equipment (deep freezer and ice-lined refrigerators).[72] Along with the PHCs, refrigeration infrastructure is also required for SHCs, ambulances, and chemists for last mile vaccine delivery. According to the government, it is mandatory to have Ice Lined Refrigerators (ILRs) and Deep Freezers (DFs) in each PHC. Moreover, the guidelines also suggest deploying vaccines carriers at SHCs and ambulances.[73] Additionally, in the context of COVID-19, vaccine carriers can be used for transporting biological samples, and viral swab samples. As per stakeholders, the optimum size of off-grid solar vaccine storage lies in the range of 100-270 litres. The study finds that there is an opportunity to deploy solar direct drive (SDD) refrigerators of 100-litres in 20,900 PHCs, solar PV with battery (SWB) powered refrigerators of 270-litres in 180,000 chemists, and solar vaccine carriers of 4-litres in 153,650 SHCs and 24,850 ambulances. Companies like Dulas and Sure Chill are already providing efficient off-grid solar vaccine storages in this market segment.[74] [75] Figure 7 illustrates the methodology and assumptions for calculating the market size for the off-grid solar vaccine storage segment.

© Dulas

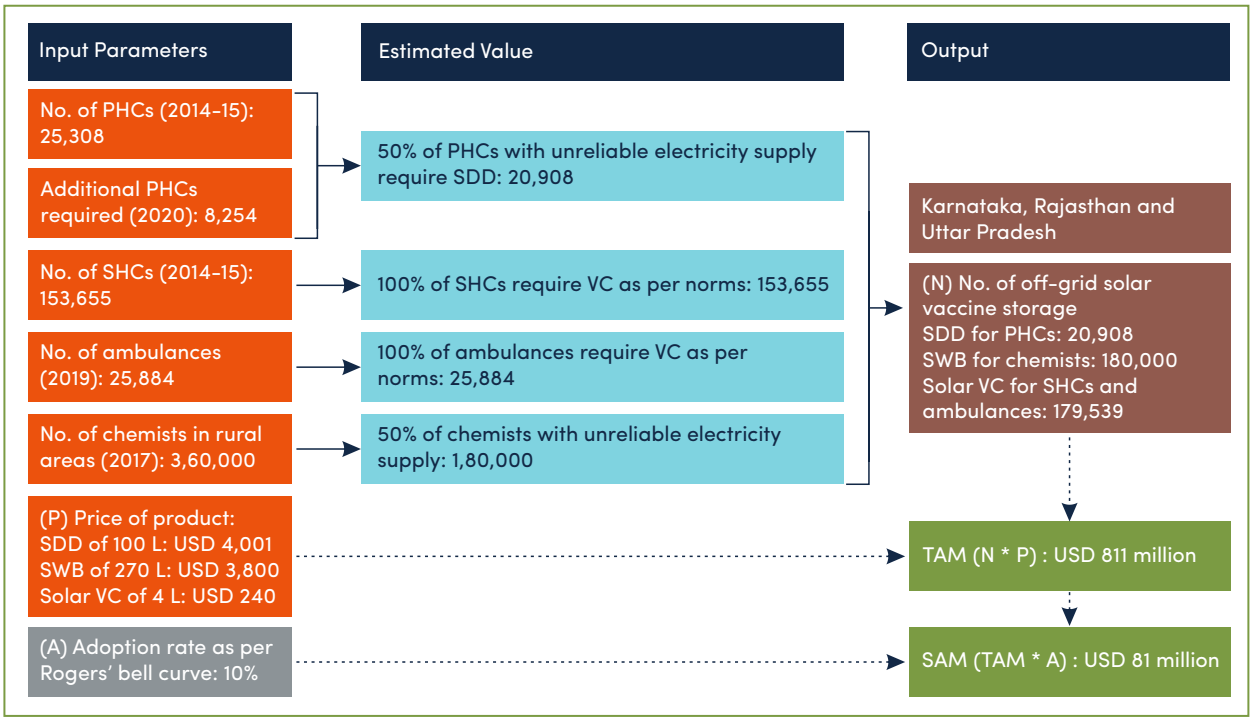
[70] Vaccine Storage and Handling; Pan American Health Organisation (Link)
[71] Vaccine Wastage Assessment: Field Assessment and Observations from National stores and Five Selected States of India; UNICEF; 2010 (Link)
[72] The State of Electricity Access for Primary Health Centres in India; CEEW; February 2019 (Link)
[73] Note: The numbers have been rounded for ease of reading. The exact numbers used for calculation of the market seize have been mentioned in Fig 5
[74] Website – Dulas (Link)
[75] Website – Sure Chill (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1.1 Market Size and Need Assessment

Solar energy powered applications can provide a reliable source of energy to healthcare facilities at a lower cost compared to diesel powered systems. To meet the deficit in electricity access, many state governments, under the National Health Mission (NHM), have provided electricity backup through diesel generators.[76] These diesel generators have significant cost implications due to high recurring costs of energy. On the other hand, renewable sources of energy (like solar PV with battery storage) are more cost-efficient mainly due to lower operating expenses. It has become more affordable for the healthcare facilities to be equipped with solar energy (both as a primary or backup energy source) to address the energy deficit.[77] With lower cost of operation and maintenance, and greater reliability, solar energy has the potential to meet the energy requirements of healthcare centres. In addition, replacing a backup diesel generator with solar alternatives for a 100-litre vaccine storage unit (~1.9 kWh per day) can eliminate up to 720 kg of carbon dioxide emissions annually.[78]

Figure 7: Calculation of market size for off-grid solar vaccine storage



[76] Powering Primary Healthcare through Solar in India: Lessons from Chhattisgarh; CEEW; July 2017 (Link)
[77] Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings: A Review of Status, Significance, Challenges and Measurement; WHO; 2015 (Link)
[78] Energy Education; University of Calgary (Link)

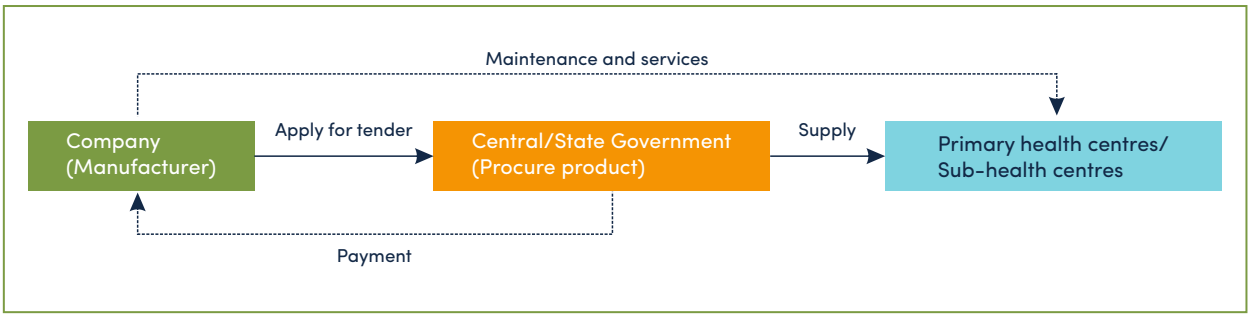
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1.2 Business Models

In India, the vaccine refrigeration market is mostly driven by government funding across varied levels of governance (i.e. national, state and district level). The most prominent way to procure vaccine refrigeration units is through a government tender.The key technical and financial criteria for shortlisting companies include (i) compliance, as per the technical standards given by WHO, (ii) the financial strength of the company; and (iii) and the commercial viability of the product according to the market demand. The government follows the Quality Assurance and Quality Control (QA/QC) procedures to ensure that products and services meet customer expectations. This is driven by the quality control department of respective governments. The tender is awarded to the company with the lowest bidding price. Figure 8 depicts this business model. However, the lengthy and cumbersome application process and delays in vendor selection discourages vendors participation. This can contribute to delayed introduction of new technologies in the market.

NGOs/foundations are improving access to finance for healthcare centres/workers through revolving funds, grants or subsidised credit for the purchase of off-grid solar vaccine storage. In this business model, the companies provide off-grid solar vaccine storage units to consumers (health care workers or community members) after an upfront payment. Through innovative financing mechanisms (such as revolving funds, grants, and concessional loans), NGOs/foundations support consumers for purchasing vaccine storages. For example, the Aga Khan Foundation provides credit to veterinary healthcare workers in Bihar through its revolving fund for purchase of vaccine storages. This credit is on an interest free equated monthly instalment (EMI).[79] This is illustrated in Figure 9. In a few other geographical areas, NGOs and development partners are supporting local governments to maintain and upgrade the vaccine refrigeration value chain. For example, the United Nations Development Programme (UNDP) is helping the Government of India to design and implement an Electronic Vaccine Intelligence Network (eVIN) in more than 521 districts, across 21 states and union territories.[80] The details of this program are profiled in Chapter 4.

Figure 8: Government driven business model for the vaccine segment

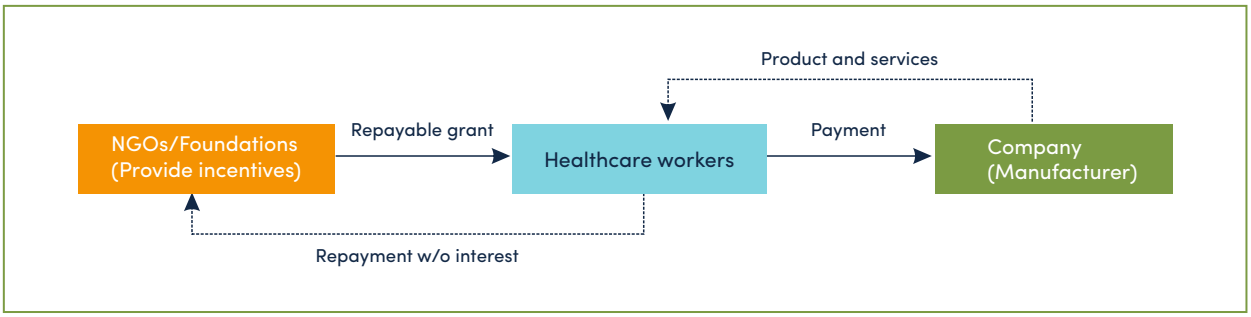


[79] Note: EMI is one part of the equally divided monthly outgoes to clear off an outstanding loan within a stipulated time frame.
[80] Web Article - Improving Vaccination Systems (EVIN); UNDP (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1.2 Business Models

Figure 9: NGOs/Foundations led business model for the vaccine segment



Box 1: Case study on off-grid solar vaccine refrigerator in Nigeria[81]

KXN Nigeria, a solar energy company, commissioned 189 off-grid solar vaccine refrigerators in 90 villages across the North-East region of Nigeria. A single refrigerator can serve a population of about 6,000 people. As a result, about 1.13 million people were vaccinated. As part of the national campaign to eradicate polio, 167 of the 189 KXN systems were funded by the National Program for Immunization, and installed in remote areas. The remaining 22 systems were funded by Rotary International Nigeria.

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3.1.3 Prevalent Technologies

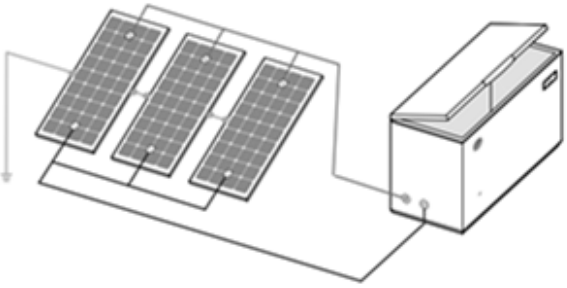
Solar Direct Drive (SDD) with PCM thermal battery is the most cost-effective technology for the off-grid solar vaccine refrigeration segment. This technology type of SDD with PCM thermal battery appliances include refrigerators, water-pack freezers and combined refrigerator water-pack freezers. These are called SDD because they are wired directly to the solar array. The cooling mechanism of this technology is a two-stage process. Firstly, solar energy is used to directly freeze water or other phase change material in an "ice-bank". Subsequently, the energy conserved in the frozen "ice-bank" is used to maintain the optimum and required temperature during the night and on cloudy days, while the solar directly powers cooling at the appropriate temperature on sunny days. This new freeze-free technology completely removes the risk of vaccine freezing, and thus has the potential to resolve many of the problems associated with off-grid solutions for vaccine refrigeration. It can enable national immunization programs to extend the cold chain in the last mile areas that might otherwise be underserved. The estimated total cost of ownership (TCO) over a lifetime period of 10 years for SDD (of capacity 100-litres) is only USD ~5,930.[82] This is the most cost-effective off-grid solar technology as this system supports energy

[81] Africa Solar Impact Studies; Solar Plaza (Link)
[82] Note: This study has assumed 10 years as a total lifetime for off-grid solar refrigerators for calculating the total cost of ownership. The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs.

3.1.3 Prevalent Technologies

supply without batteries. The average maintanance cost of an SDD is also the lowest among all the other technologies and the average operating cost per litre over its useful life is only USD 8.86.[83] SDD requires only eight hours of sunlight to store thermal energy for a minimum of 78 hours of autonomy at an ambient temperature, with a holdover time of 91 hours.[84]

Figure 10: Design of Solar Direct Drive (SDD) system for off-grid solar vaccine storage

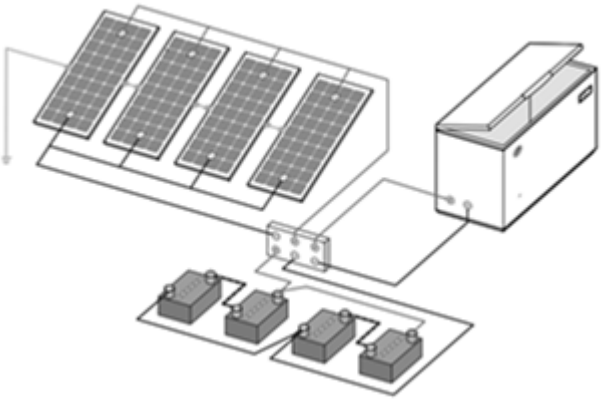


The more commonly used technology in off-grid and weak-grid areas are solar with battery systems (standard capacity 100-litres). The solar panel converts solar energy into electrical energy and stores it in the electrochemical batteries (lead acid or lithium ion). The compressor of the system keeps the battery bank in a shallow cycle mode by shutting off the refrigerator compartment to prevent battery discharge beyond its permissible limit. The PV system keeps the refrigerator compartment running while shallow cycling the battery, even during the most severe weather conditions. The estimated TCO over a lifetime period of 10 years is ~USD 6,100 for a 100-litre system.[85] The higher cost is attributed to the cost of regular solar battery replacement. However, in India, the majority of the health centres are still using diesel generators to fulfil primary energy needs. The TCO for diesel-based vaccine refrigerators is ~USD 7,040 over a period of 10 years.[86] Off-grid solar systems enable a savings of more than USD 900 per refrigerator, considering a lifetime period of 10 years. Given the cost savings and environmental benefits, there is a need to promote off-grid solar-based storage units to provide reliable energy for storing vaccines at healthcare centres. It is worth noting that a grid-connected ILR is the cheapest technology with an estimated TCO of ~USD 4,900 over the lifetime period of 10 years. However, the challenge of a weak-grid, with frequent electicity outages, implies that the SDD system is the most affordable system for ensuring the reliable storage of vaccines. Figure 12 and 13 highlights the TCO of vaccines storage as per different types of technologies such as grid-connected ILR, SDD, solar with battery, and ILRs running on diesel generators for weak-grid areas.

Note: Specific assumptions for estimation of TCO

- TCO of ILRs running on diesel generators does not include capital cost or maintenance costs of the diesel generator system
- Average cost of energy is attributed to the cost of grid electricity and cost of diesel

Figure 11: Solar with battery system for off-grid solar vaccine storage

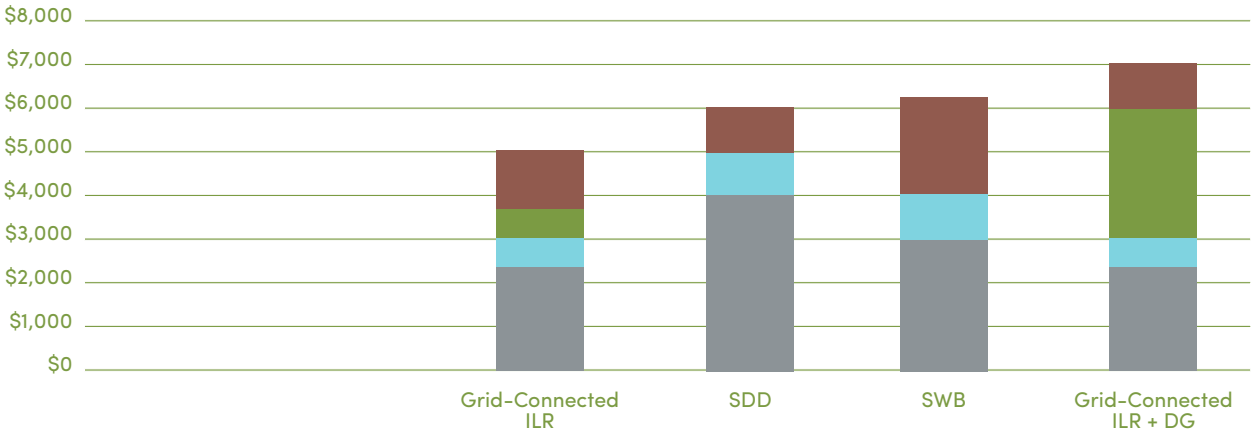


[83] Intellecap Analysis
[84] Note: Autonomy can be referred to as backup, discharge time, or runtime. Holdover time is the time taken by the equipment to raise the internal cabinet temperature from its cut-off temperature to the maximum temperature limit as per its recommended range.
[85] Note: The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs.
[86] The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs.

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

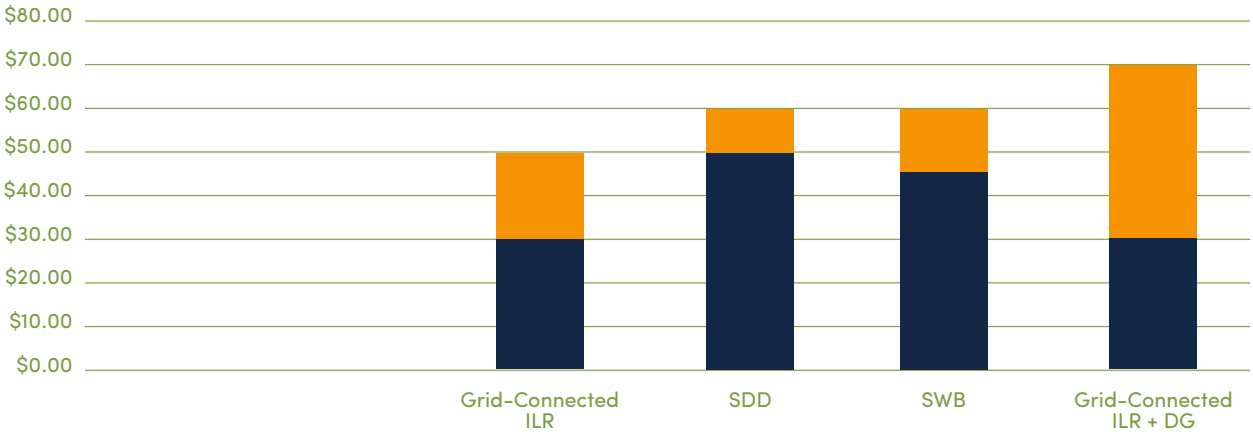
3.1.3 Prevalent Technologies

Figure 12: Total cost of ownership over a lifetime period of 10 years of vaccine refrigeration



	Grid-Connected ILR	SDD	SWB	Grid-Connected ILR + DG
Average Cost of Maintenance over lifetime	$1,036	$886	$1,162	$1,036
Average Cost of Energy over lifetime	$548	$0	$0	$2,682
Average Cost of Installation	$748	$1,042	$1,042	$748
Cost Price of the product (size-100L)	$2,573	$4,001	$3,442	$2,573

Figure 13: Average cost per litre over a lifetime period of 10 years of vaccine refrigeration



	Grid-Connected ILR	SDD	SWB	Grid-Connected ILR + DG
Average OPEX over lifetime per Litre	$15.84	$8.86	$16.12	$37.17
Average CAPEX per Litre	$33.21	$50.43	$44.84	$33.21

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1.3 Prevalent Technologies

Box 2: Case study on SDD technology for storage of heat-sensitive vaccines at the right temperature[87]

A PHC in Karnataka has installed a Sure Chill SDD Vaccine Storage. The SDD vaccine storage keeps the temperature between 2°C to 8°C (not allowing vaccines to freeze). This technology is functional during power outages, thereby leading to a reduction in the wastage of vaccines. The PHC has also started an immunization program because of the availability of a reliable storage mechanism. The upfront investment support for the vaccine storage has been provided by an NGO. The PHC has the capacity for approximately 800 immunization dosages per month.

3.1.4 Challenges and Opportunities

The two key challenges hindering the growth of the off-grid refrigeration market for vaccines are the limited interest of quality certified manufacturers participating in government tenders, and a lack of awareness of these tenders among stakeholders. Many state governments and donor agencies require product testing for refrigeration units. For example, a recent tender for solar powered refrigerators by GIZ in India requires the manufacturer to get their equipment tested by a laboratory accredited with the Bureau of International Standards (BIS), the National Accreditation Board for Testing and Calibration Laboratories (NABL) or the Ministry of New and Renewable Energy (MNRE).[88] In addition to the lack of awareness about government tenders, these processes can involve a time consuming and complicated tendering process, which discourages companies from applying. For example, delays in payment clearance can decrease the working capital of the companies and impact the scale of production. To mitigate these effects, companies tend to increase the price of the products. This reduces financial viability, as the government chooses the least cost bidder. Delays in receiving approval from the government is another critical challenge for companies. Sustainable technologies in rural areas have limited implementation due to a lack of awareness, and limited recognition of the viability of new technologies among stakeholder groups (including consumers, development partners, government etc.). For example, despite the higher operating costs of the diesel system, many of the PHCs still prefer diesel generators over renewable energy systems.

Along with off-grid solar refrigeration for vaccine storage, there is also an increased demand for refrigeration in pathology labs to ensure safety of testing samples, especially in the current pandemic. Further, there is need for refrigeration at bloods banks and chemists. The Government of India has formulated a policy to establish one blood bank in every district with adequate infrastructure and trained manpower. This is expected to increase refrigeration demand for blood banks in the near future. Refer to the box for a short description on the blood banks ecosystem. Furthermore, the government's requirement of higher performing cost-effective and quality products amidst current COVID-19 concerns has the potential to increase demand for off-grid solar vaccine storages.

[87] Annual Report 2018-19, SELCO Foundation (Link)
[88] Web Article - GIZ Floats Tender for Solar-Powered Cold Storage Units to Help Farmers; Mercom India; Nov 2020 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.1.4 Challenges and Opportunities

Refrigeration in blood blanks in India[89]

India needs 8.5 million units of blood annually; presently only 5 to 5.5 million units are collected. The Ministry of Health and Family Welfare has formulated a policy to have at least one blood bank in every district. As of July 2019, there were 3108 blood banks in India. However, 76 districts still do not have any blood banks. There is apotential to supply off-grid solar refrigerators to the blood banks. The typical capacity of one off-grid solar refrigerator for a blood bank is 57.5-litres, which costs USD 3,000. Thus, considering the installation of SDD blood storage units at 76 blood banks, the estimated market opportunity is USD 0.23 million. This market size could increase, considering the need for off-grid solar refrigerators at blood banks in districts with unreliable electricity supply.

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[89] Press Release on Blood Banks Infrastructure; GoI (Link)

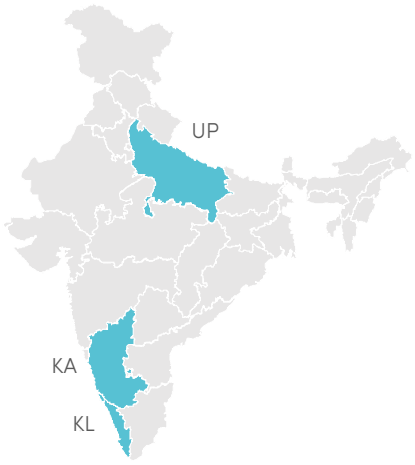
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.2 Households

3.2.1 Market Size and Need Assessment

The total addressable market for household off-grid solar refrigerator is USD 4.1 billion, while the segmented addressable market is USD 406 million.[90] According to Roger's bell curve, the segmented market has been calculated at 10%, considering an early adoption rate of new technology.[91] In India, majority of the rural households do not own large electrical appliances (such as refrigerators, air conditioners etc.) due to weak-grid. The average consumption of electricity in rural households is less than 50% of the national average consumption of electricity in households.[93] A recent pilot study on rural electrification in India found that 40% of households (across four major states of Bihar, Uttar Pradesh, Rajasthan, and Odisha) do not receive 24x7 adequate and reliable grid electricity supply. The lack of reliable sources of electricity can damage or limit the use of appliances such as AC refrigerators. As of 2015-16, only 16.4% of rural households owned refrigerators in India.[94] Studies indicate that the market for refrigerators starts to take off when the average annual per capita income for a household is USD 2,500.[95] Out of the total 201 million rural households in India, 8.25% generate an income greater than USD 1,608 per annum (USD 134 per month).[96] These rural households that have the ability to pay for consumer durables such as refrigerators and televisions can be targeted. As per the UN's Food and Agriculture Organization, a lack of access to refrigeration technology in the developing world (including India) results in a 40% pre-market loss of food production.[97] People living in off-grid and weak-grid communities also face food storage issues, making their need for refrigeration particularly high. Hence, there is a need to promote off-grid solar refrigerators among rural households in these areas.

Figure 14: Potential states for off-grid solar refrigeration for rural households



The states with high potential for piloting off-grid solar refrigeration are Kerala, Uttar Pradesh, and Karnataka. These states have a significant number of rural households without refrigerators and a high proportion of households with income greater than USD 1,608 per annum.[98] These states have been selected based on a mapping of top states, which took two main parameters into consideration: (I) the percentage of rural households owning refrigerators is less than 16.4% (all India average) and (ii) the percentage of rural households earning at least USD 1068 annually is closest to the median value (i.e. 9.59%). Some development partners (such as GIZ and SELCO Foundation) are also showing interest in implementing programs on off-grid solar refrigerators across market segments in these states.

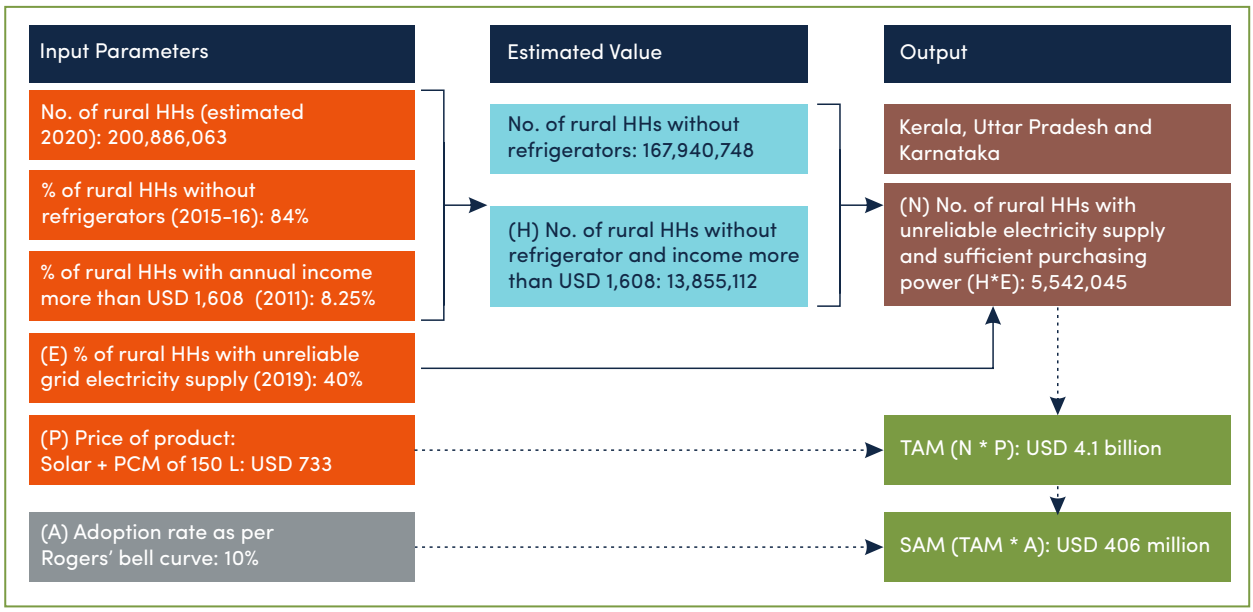
[90] Intellecap Analysis
[91] Note: The Roger's Bell Curve analysis classifies users for the adoption or acceptance of a new product or innovation into various categories, based on their willingness to accept new technology or an idea.
[92] Power to the People: A Case for Energy-Efficient Appliances in Rural India; Economic Times; August 2020 (Link)
[93] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[94] National Family Health Survey; Ministry of Health and Family Welfare; GoI (Link)
[95] Urban World: Cities and the Rise of the Consuming Class; McKinsey Global Institute; June 2012 (Link)
[96] Social and Caste Economic Census 2011; GoI (Link)
[97] Seeking End to Loss and Waste of Food Along Production Chain; FAO; 2018 (Link)
[98] National Family Health Survey; Ministry of Health and Family Welfare; GoI (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.2.1 Market Size and Need Assessment

A rise in rural incomes is expected to increase market demand for energy efficient household appliances including off-grid solar refrigerators. Currently, in households, there are several traditional technologies (such as clay pots), which are being used to keep food items cooler than ambient temperature, and avoid food spoilage. Some rural households with higher consumption expenditures and adequate electricity supply are using standard on-grid refrigerators. The improving standards of living in rural areas has also led to a wider acceptance of off-grid solar refrigerators in the past few years. In this segment of refrigerators, the average capacity of refrigerator-freezer combination units was 27% more than basic off-grid solar refrigerators (without freezers). The most common product size for off-grid solar refrigerators (without freezers) is between 50 and 99 litres, and the most common size for refrigerator-freezer combination units is between 150 and 249 litres.[99] The most viable capacity of off-grid solar refrigerator for rural households is 150-litres (as suggested by stakeholders). Companies like Sinfin and Tan90 are providing efficient off-grid solar refrigerators in this market segment.[100] [101] Figure 15 depicts the methodology for calculating the market size for the rural households' segment.

Figure 15: Calculation of market size for off-grid solar refrigerator for the household segment



[99] Off-Grid Appliance Performance Testing: Results and Trends for Early-Stage Market Development; Lai, E., Muir, S. & Erboy Ruff, Y; May 2019 (Link)
[100] Website – Sinfin (Link)
[101] Website – Tan90 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

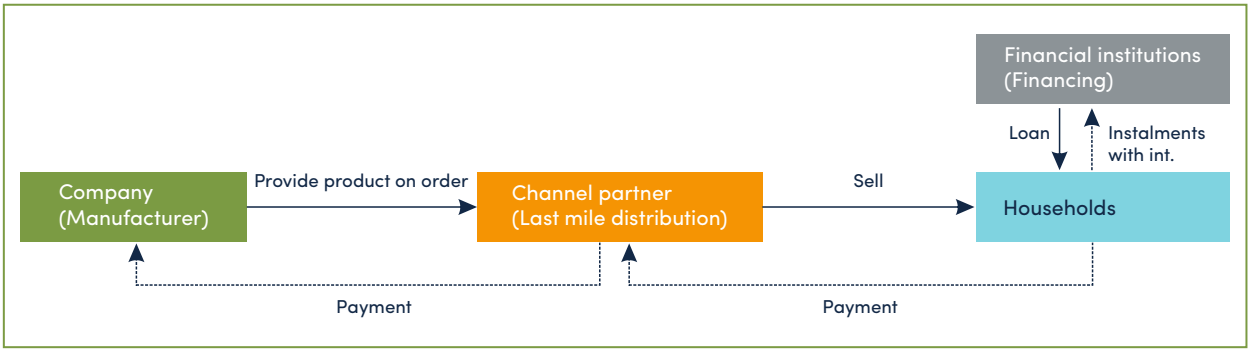
3.2.1 Market Size and Need Assessment

The use of energy efficient appliances, including solar refrigerators, can lead to substantial energy savings and reduce consumption expenditure for rural households. A recent study suggests that distributed solar DC appliances including refrigerators will propel market growth in the near to medium term. The study finds that in the near term, all rural households covered under the government's Saubhagya initiative are likely to own a minimum of two ceiling fans, two LED (Light Emitting Diode) bulbs, and a television set. In addition, in the near term, 30% of these households will own a refrigerator and an air cooler, due to rising incomes and improved standards of living. The majority of these households are likely to purchase standard refrigerators with low energy efficiency ratings readily available in the rural market, implying an increase in energy demand. The application of low efficiency refrigerators can have a detrimental impact on the income of consumers, as well as on the environment. To meet this rising energy demand for inefficient appliances from rural households, the government will need to increase the generation of electricity by 29 billion units (kWh) per year. This could require an investment of ~USD 9 billion.[102] The replacement of standard appliances with improved energy efficient appliances, including solar refrigerators, can be highly beneficial. Estimates by the International Financial Corporation (IFC), indicate that if rural households adopt these energy efficient appliances, they can expect energy savings of 58% and prevent 14 million tons of CO2 emissions per year.[103]

3.2.2 Business Models

There is low penetration of off-grid solar refrigeration products among households despite direct sales via channel partners or support from NGOs/Foundations. The prominent channel partners for off-grid solar refrigerators are existing distributors of off-grid solar products (home lighting system, panels, batteries, etc.). The priority customers are households in weak-grid and off-grid areas. In the direct sales business model, manufacturers supply products via distribution channels such as stockists, wholesalers and retailers. These channel partners may also provide after-sales service and enable consumer financing for households by fostering partnerships with financial institutions. Currently, direct consumer financing is available for lower cost solar products (such as solar home systems, lighting, panels etc) by Micro Finance Institutions (MFIs). There has not been any significant financing for off-grid solar refrigerators by MFIs due to the high capital cost of the technology.

Figure 16: Direct sales business model for the household segment



[102] Note: To generate 29 billion kWh of electricity a year, the government will need to install 18,125 MW of solar power plants. The value of investment has been calculated considering the cost of 1 MW solar power plant to be USD ~0.5 million.
[103] Web Article - Power to the People: A Case for Energy-Efficient Appliances in Rural India; Economic Times; August 2020 (Link)

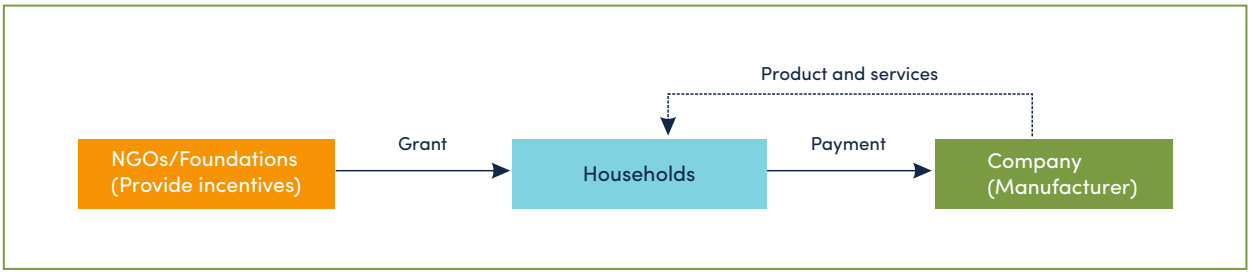
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.2.2 Business Models

NGOs and foundations support household members to purchase off-grid solar refrigerators by providing financial assistance (in the form of grants, for example). Household members are able to access the product due to the NGO/foundation provided grant support (repayable grant in some cases). Grant support is needed to drive the market growth of off-grid solar refrigerators in the household market segment. For example, the Green Innovation Centre of GIZ is supporting a few households in Karnataka by providing smaller off-grid refrigerators for a family of four members. This can be used to store and avoid the spoilage of freshly cooked food, daily.[104]

© Devidayal Solar

Figure 17: NGO/foundation driven business model for the household segment



Box 3: Case study of a pay-as-you-go (PAYG) solar refrigerator in Kenya and Uganda[105]

Youmma offers a small efficient refrigerator that runs on a single solar panel, and a PAYG system makes it affordable even for families with very low household income. This product is offered in Kenya and Uganda. Youmma partnered with M-Kopa, to offer the refrigerator as part of a solar home system. The refrigerator has battery storage that can store power for one-and-half day (to provide support in days without sunlight).

The refrigerator also uses an efficient compressor, which ensures energy savings. The households pay a small amount via their mobile phones (PA) on a daily basis. This payment is incurred by the household till the cost of the system completely paid off. The company effectively finances the sale of the refrigerator and SHS through deferred payments and recovers its cost over the lease period. The company found that households were saving ~USD 4.83 a week (on average) by reducing food spoilage and costs incurred on trips to the market. Some households reported savings up to 50% of their total income.

[104] Primary Research
[105] Web Article – Pay-as-you-go solar fridge helps African families save money and time; April 2020 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.2.3 Prevalent Technologies

Solar PV with PCM thermal battery is the most viable technology for consumers considering its cost-economics in comparison to other solar-powered refrigerators. In this technology, solar panels convert solar irradiation into electrical (DC) power. The electrical power drives the compressor to circulate the refrigerant through a vapour compression refrigeration loop that extracts heat from an insulated enclosure. The enclosure includes a thermal reservoir and a PCM. This material freezes as heat is extracted from the enclosure. This entire process effectively creates an ice pack, maintaining temperature inside the enclosure in the absence of sunlight. The estimated TCO over a lifetime period of 10 years of solar PV with PCM thermal battery (150-litre) is the lowest for households at ~USD 1,130.[106]

Figure 18: Solar refrigerator with battery for households

Solar PV with battery system is the most widely used technology due to better supply chains. Solar PV with battery operates 24x7 with the use of an appropriate battery designed for overnight cooling. For a 150-litre refrigerator, solar PV with battery requires a 200 Wp solar panel and a 150 Ah battery in a 12 V system. Solar panels charge the battery with DC power via a charge controller/regulator. A charge controller protects the batteries from over charging by supplying the optimum amount of power to ensure a long battery life. The DC power from the solar panels and battery drives the compressor of the vapour compression system. Excess energy is stored in the batteries to continue operations during the night. The TCO of a solar PV with battery system (150-litre) over a lifetime period of 10 years is ~USD 1,225. In weak-grid areas, DC refrigerators are typically provided with an adapter for interoperability. The adapter supports AC/DC interoperability functionality, which helps appliances in switching from DC power consumption to AC power consumption, and vice versa according to the requirement.

AC refrigerators connected to grid electricity have the lowest TCO (~USD 610), over the lifetime period of 10 years. However, a lack of reliable electricity is a major constraint in rural areas, and, as a result, some customers are dependent on back-up diesel generators. Furthermore, customers in rural areas mostly purchase AC refrigerators with 2- or 3- star ratings. These have efficiency levels of up to 40-50%, which are lower than 5-star rating or other efficient refrigerators.[107] Considering these factors, the average operating expenditure of AC refrigerators running on a diesel generator rises significantly to ~USD 11.74 per litre over the lifetime period of 10 years. This makes it unviable for rural households. Figures 19 and 20 highlight the total cost of ownership and per litre average OPEX and CAPEX over 10 years for household refrigerators.

Note: Specific assumptions for estimation of TCO

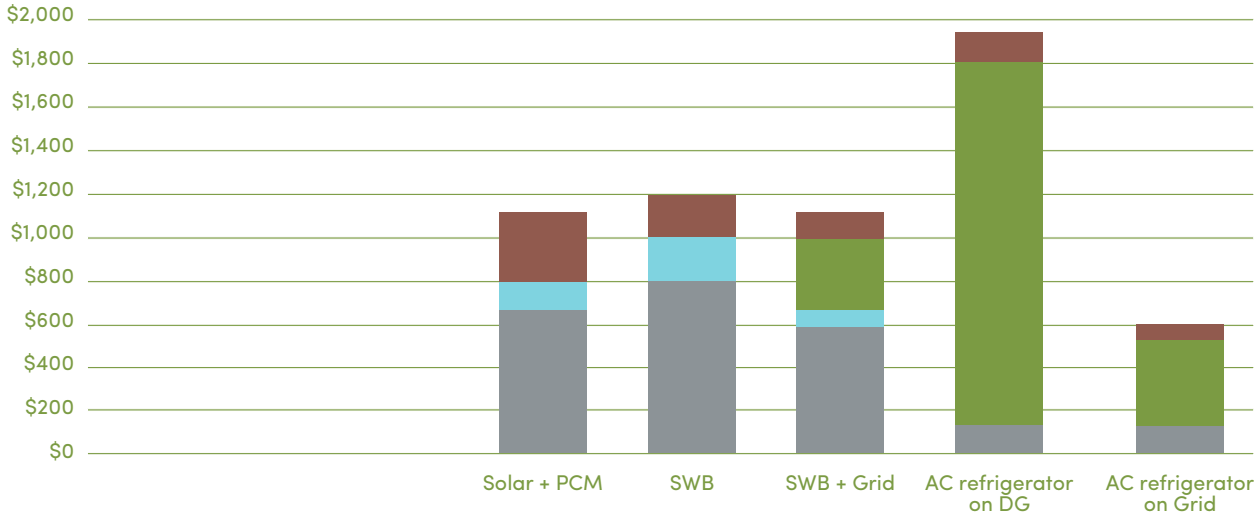
- Cost of installation of an AC refrigerator is included in the capital cost, as it is sold as a play and plug unit
- TCO of AC refrigerator on diesel generators does not include capital cost or maintenance costs of the diesel generator system
- Average cost of energy depends on the cost of grid electricity and cost of diesel
- Solar with battery system and grid connectivity has smaller solar array and lower battery capacity considering compatibility with grid

[106] Note: The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs.
[107] Star Labels as per BEE (Link).

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

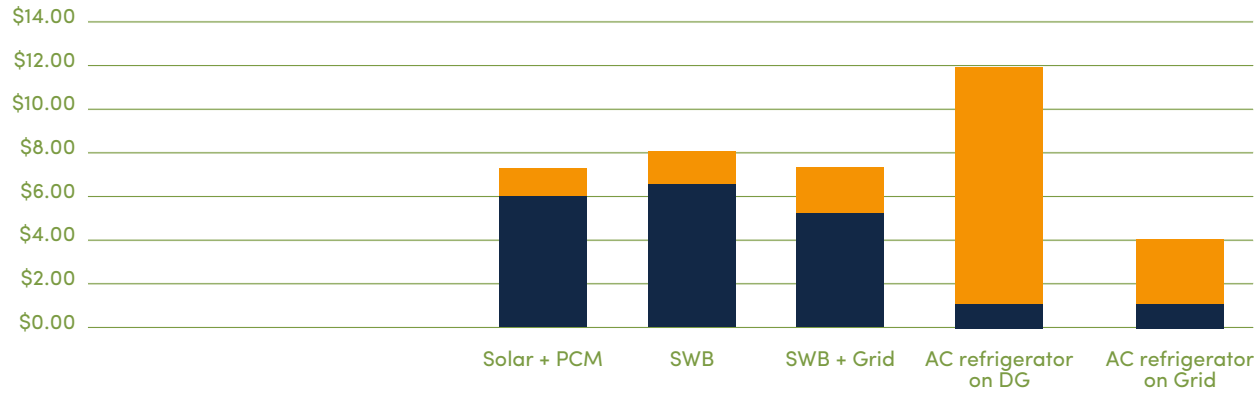
3.2.3 Prevalent Technologies

Figure 19: Total cost of ownership over a lifetime period of 10 years for household refrigerators



	Solar + PCM	SWB	SWB + Grid	AC refrigerator on DG	AC refrigerator on Grid
Average Cost of Maintenance over lifetime	$267	$200	$93	$67	$67
Average Cost of energy over lifetime	$0	$0	$291	$1,694	$409
Average Cost of Installation	$133	$133	$133	$0	$0
Cost Price of the Product (size-150L)	$733	$892	$625	$133	$133

Figure 20: Average cost per litre over a lifetime period of 10 years of household refrigeration



	Solar + PCM	SWB	SWB + Grid	AC refrigerator on DG	AC refrigerator on Grid
Average OPEX over lifetime per Litre	$1.78	$1.33	$2.56	$11.74	$3.17
Average CAPEX per Litre	$5.78	$6.84	$5.06	$0.89	$0.89

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.2.3 Prevalent Technologies

Box 4: Case study on off-grid solar refrigeration at household level in India[108]

SELCO India installed off-grid solar refrigerators in households in rural parts of Karnataka. The households with unreliable power supply were provided with a grant from SELCO to install off-grid solar refrigeration systems. This solar PV with battery technology provides a battery backup for 24 hours and uses an eco-friendly cooling agent (R-134) in the 150 L refrigerator. The refrigerators are used for storing perishable food items and milk products. For women in rural communities, owning a refrigerator is perceived to be associated with social capital, indicating a "wealthy" and "happy life".

3.2.4 Challenges and Opportunities

Off-grid solar refrigerator for the household segment has a lower market opportunity compared to other market segments, as consumers cannot yield direct benefits like income. Poor access to finance is a critical barrier in the promotion and adoption of off-grid solar refrigerators in this segment. This includes limited availability of debt and working capital to invest in research and development, and manufacture affordable appliances for companies to manage supply chains in remote areas. The key challenges with off-grid consumer financing include weak recovery systems, a lack of collateral and margin money, and limited interest from commercial lenders. Moreover, limited consumer awareness, poor brand recognition of off-grid solar refrigeration products (e.g. consumers prefer popular brands such as Samsung and LG) and a lack of quality assurance impacts consumer confidence, which results in low adoption rates in rural areas. Further, consumers face several challenges regarding performance and reliability due to the lack of a supply chain. The underdeveloped supply chain and after-sales network is mostly due to the remoteness of consumer locations.

Companies need to create awareness among consumers and policy influencers about the availability and the economic and environmental benefits of the technology. It would help them attain economies of scale and make the product commercially viable for the market. There is an opportunity for market enhancement under the Ministry of New and Renewable Energy (MNRE) scheme, on 'Scale Up of Access to Clean Energy for Rural Productive Use'. This scheme promotes the application of new renewable energy technologies (such as solar refrigerators, solar dryers and solar aerators) for rural productive uses/livelihoods in the under-served states such as Assam, Madhya Pradesh and Odisha. The overall demand for off-grid solar refrigerators is expected to increase in the near future with improving living standards of rural consumers.

[108] Sustainable Energy for Socio Economic Development; SELCO India; 2017 (Link)

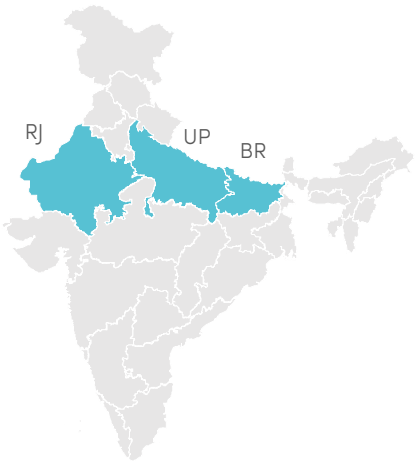
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.3 Micro-Enterprises

3.3.1 Market Size and Need Assessment

The total addressable market of off-grid solar refrigeration for micro-enterprises segment is USD 634 million.[109] Considering that 10% is the rate for early adoption technology, the segmented addressable market for off-grid solar refrigerators for micro-enterprises is USD 63 million. The micro-enterprises considered for the study are 'kirana' stores in rural areas that have significant demand for off-grid solar refrigerators. This is due to the growing requirements for cold water, ice-creams and cold drinks. These stores occupy a large share of the grocery and retail market in India. It is estimated that there is one kirana store per 100 people in India.[110] A study on rural electrification in India found that 40% of the micro-enterprises (across the four states of Bihar, Uttar Pradesh, Rajasthan, and Odisha) do not receive 24x7 grid electricity supply.[111] Thus, out of 9.44 million kirana stores in rural areas, 3.78 million are likely to be unsatisfied with their grid electricity supply. The key reasons are frequent power cuts, unreliable electricity supply, and non-availability of electricity during peak hours.

Figure 21: Highest potential states for off-grid solar refrigeration among micro-enterprises



Bihar, Rajasthan, and Uttar Pradesh are the states with highest potential for piloting off-grid solar refrigeration in rural areas. Out of the four states previously identified, these are the states with the highest number of kirana stores, with as many as 40% of rural micro-enterprises without reliable and adequate grid electricity supply.[112]

The use of off-grid solar refrigerators can reduce the potential losses incurred by kirana stores by providing a reliable energy source for cooling. Currently, the majority of these stores use traditional clay coolers to keep products cooler than ambient temperature. They also have small 'visi coolers' to store small perishable commodities (like chocolates and candies) and beverages. Refer to the box for more details. Some stores in weak-grid areas use AC refrigerators, with an expectation of uninterrupted supply of grid electricity. However, insufficient cooling due to poor electricity supply can lead to spoiled commodities, thereby resulting in a loss of income for the owner of the kirana store. This exemplifies the need for off-grid solar refrigerators in rural markets. The most preferred customer segment is large kirana stores, which have permanent structures and inventories worth more than USD 2,000 (suggesting the quantum of scale of operations). These stores can potentially afford off-grid solar refrigerators. Hence, the primary customers for this technology may be 0.68 million large kirana stores (18% of the kirana stores[113]) with unreliable grid electricity supply in rural areas. The optimum capacity of refrigerators required for these large kirana stores is 268-litres (as suggested by stakeholders). Companies like Devidayal Solar Solutions and Phocos are providing efficient off-grid solar refrigerators in this market segment.[114,115] Figure 22 depicts the methodology for calculating the market size for the micro-enterprise segment.

[109] Intellecap Analysis
[110] Local Kirana Shops Offer Various Business Opportunities in Retail and Distribution Market in India; Mitsui & Co. Global Strategic Studies Institute; October 2018 (Link)
[111] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[112] Rural electrification In India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[113] Rural electrification in India: Customer Behaviour and Demand; The Rockefeller Foundation; February 2019 (Link)
[114] Website – Devidayal Solar Solutions
[115] Website - Phocos

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.3.1 Market Size and Need Assessment

Visi Coolers in India

In India, there are three types of 'visi' coolers available i.e. chest door, single door and the double door. The capacity of 'visi' coolers ranges from 130-litres to 1000-litres for single and double door, and 15-litres to 35-litres for chest door (commonly used for chocolate storage). These coolers are mostly used for storing cold beverages, milk and dairy products in shops. In 2017-2018, the market size of 'visi' coolers was 0.3 million units.[116] In 2017, Coca-Cola India started installing of solar 'visi' coolers in rural areas with unreliable electricity supply. By 2020, the organization plans to install 1,000 solar coolers in female-owned, small retail shops in rural India through its CSR fund.[117]

'Visi' coolers and refrigerators differ on two key aspects i.e. temperature variance and physical attributes. 'Visi' coolers are cooling units that usually maintain a temperature range between 1°C to 10°C, while the temperature for refrigerators can also be set below 0°C. In terms of physical structure, 'visi' coolers have a transparent display to showcase the products (more popularly used in retail shops) in comparison to the opaque structure of most refrigerators.

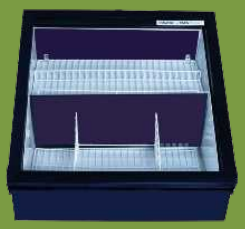
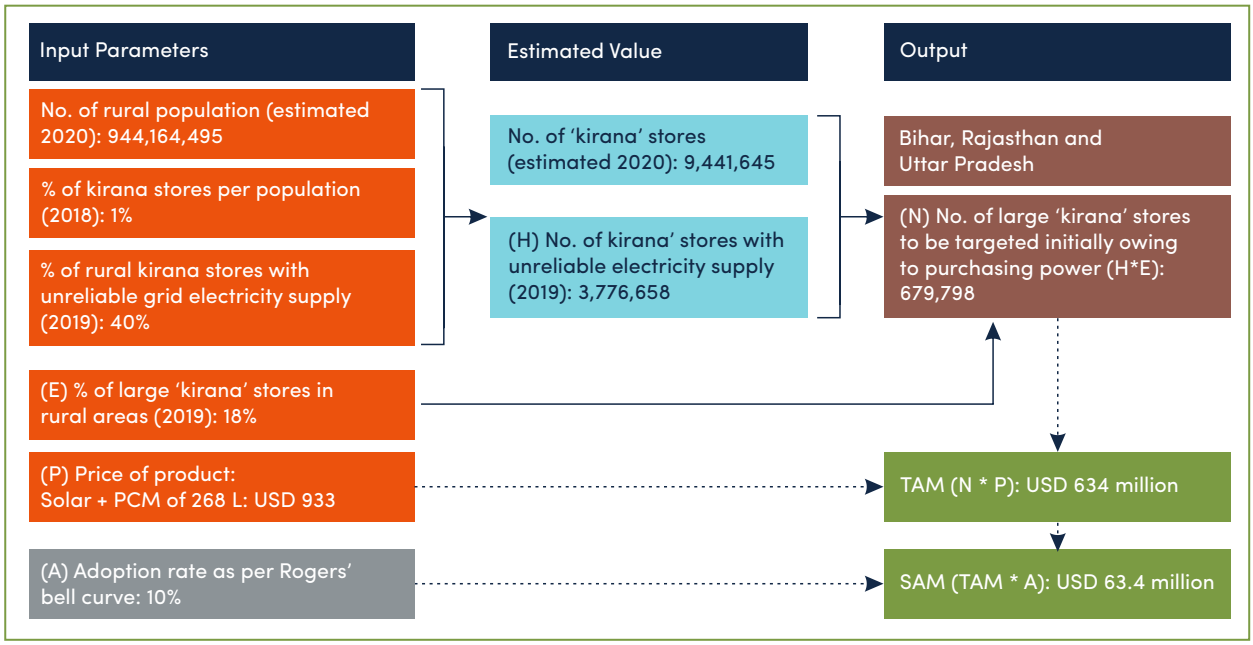


Figure 22: Calculation of market size for off-grid solar refrigerator for the micro-enterprise segment



[116] Demand Analysis for Cooling by Sector in India in 2017; Bureau of Energy Efficiency; 2017 (Link)
[117] Web Article - Solar Coolers Light Up Lives Across Villages; Coca-Cola India; 2017 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

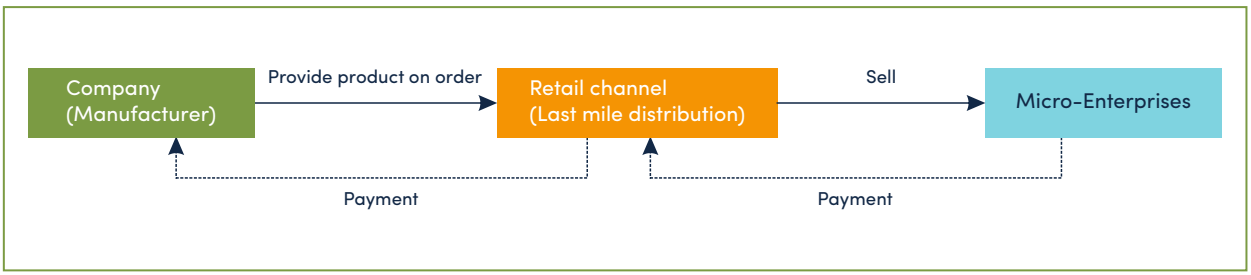
3.3.1 Market Size and Need Assessment

Kirana stores can earn a premium on chilled/cooled products in the summer season by using off-grid solar refrigerators in weak-grid and off-grid areas. The demand for chilled/cooler products (such as cold beverages, chocolates, dairy products etc.) in rural areas is increasing due to higher temperatures and longer summers. The findings of a recent pilot study in India established that micro-enterprises using stand-alone solar refrigerators can increase profits by USD 57 per month (potential to gain up to USD 114 per month).[118] In select cases, the owners of the kirana store also allow household members to store their produce in their refrigerators for small amounts of money. These innovative models provide an additional income generating opportunity for these micro-enterprises. In addition, the impact of the existing pandemic (COVID-19) has re-emphasised the importance of last mile availability of essential commodities (such as fruits and vegetables, dairy products, etc). The majority of these commodities require chilling at distribution points to maintain their quality for a significant time. This can be an opportunity for kirana stores to diversify their range of products and earn higher profit margins. Hence, there is significant market potential for off-grid solar refrigerators in this segment.

3.3.2 Business Models

Direct to retail channel is the most preferred business model in the rural areas for off-grid solar refrigeration. The existing distributors of other appliances and allied sectors (such as solar home system, solar panel, and electrical contractors) play an important role in this business model. These distributors collaborate with manufacturers to become distributors of off-grid solar refrigerators. They have a well-established supply chain and after-sales service network in the rural areas. The manufacturer receives direct payment from either the consumer or the distributor. In some cases, the distributors work as stockists (only providing warehousing facilities) as well as operations and maintenance partners. Companies (like Phocos) supply their off-grid solar refrigerators via their established sales channels.[119] These are sold to owners of kirana stores and roadside restaurants.

Figure 23: Direct to retail business model for the micro-enterprise segment



[118] Use Cases and Cost Breakdown of Off-Grid Refrigeration Systems; Efficiency for Access Coalition; May 2020 (Link)
[119] Website – About Phocos (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.3.2 Business Models

The other business models include partnerships with large corporates. Large corporates such as Amul, Coca-Cola and Mother Dairy provide refrigerators to small shop owners at a negligible cost (and sometimes free) and recover investment from the product margins. This business model helps large corporates to advertise their brands in rural areas as well as utilise Corporate Social Responsibility (CSR) funds. Off-grid solar refrigeration companies can partner with these large corporates to enhance their market share in this segment.

NGOs/foundations are enabling consumers to purchase off-grid solar refrigerators by providing grant support. They support micro-enterprises either by providing direct grants for the purchase of a refrigerator or by enabling margin money through banks/MFI loans, thus ensuring the manufacturer (enterprise) gets direct payment from the consumers who are supported by NGOs/foundations. For example, SELCO Foundation provided a margin money grant to a micro-enterprise owner to buy multiple off-grid solar appliances (including a refrigerator) in a remote tribal location in the state of Karnataka. The owner was provided with margin money (~20% of loan amount) and was then introduced to financial institutions by SELCO to get a loan for buying the products.

Figure 24: Partnership business model between retail shops and large corporates for the micro-enterprise segment

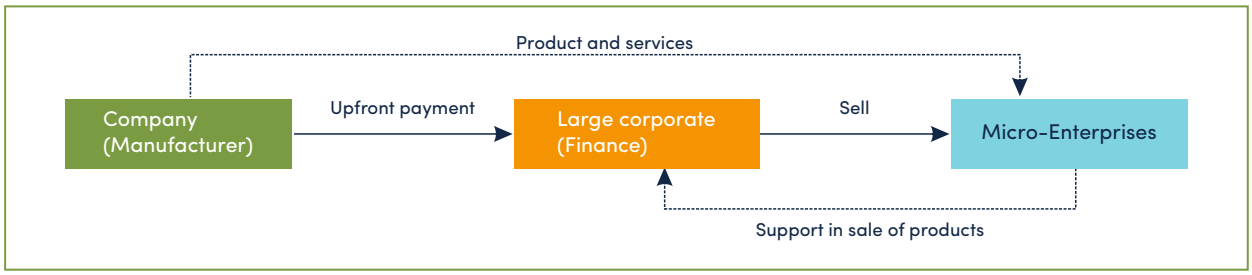
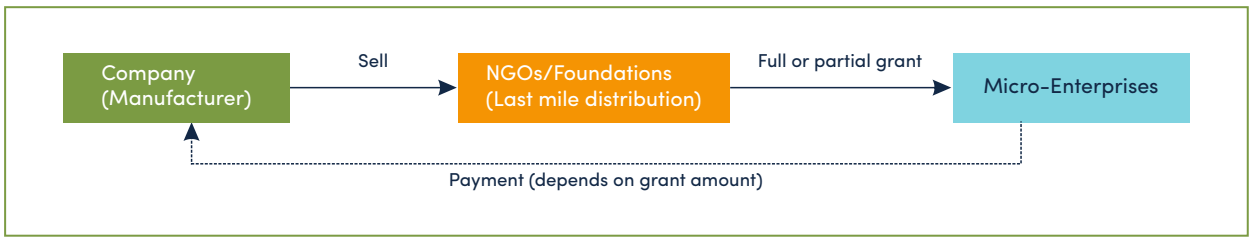


Figure 25: NGOs/Foundations driven business model for the micro-enterprise segment



3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.3.3 Prevalent Technologies

Currently, Solar PV with battery technology is being offered by companies in rural areas for this segment. This technology can operate 24x7 with the use of an appropriate battery and is designed for overnight cooling. The technology for a 268-litre refrigerator requires a 0.5 KW solar array and two batteries of 120 Ah each. These are typically composed of a number of 12 V lead-acid batteries or lithium-ion batteries. The total battery voltage is usually 12, 24, 26 or 48 V. The refrigerator uses a DC compressor that can also run directly on the battery. The estimated TCO over a lifetime period of 10 years for this technology is ~USD 1,490.[120] However, storing heat is relatively cheaper than storing electricity. Hence, some companies prefer PCM thermal batteries over lithium-ion battery for off-grid refrigeration. The TCO (~USD 1,470) of a PCM thermal battery based off-grid solar refrigerator is marginally lower than solar PV with battery systems. Refrigerators are being provided with AC/DC interoperability functions in weak-grid areas. This provides customers the flexibility to operate a system that supports both AC and DC. This allows them to charge the batteries with grid electricity as well as use the refrigerator on an AC power supply. A few companies like Cygni and Devidayal Solar Solutions have developed an innovative technology for incorporating AC/DC functionality in off-grid solar refrigerators. However, the market for a hybrid appliance with a single input (mainly AC) and the integrated battery is at a nascent stage. This is mainly due to the lack of infrastructure at the household and micro-enterprise level. The operating cost of AC refrigerators running on diesel generators is the highest at USD 10 per litre over a lifetime period of 10 years, mainly due to the energy costs. Figure 27 and 28 below highlight the TCO and average CAPEX and OPEX over 10 years for refrigeration technologies in the micro-enterprises segment.

Figure 26: Solar PV with battery technology for off-grid refrigerators for micro-enterprises

Note: Specific assumptions for estimation of TCO

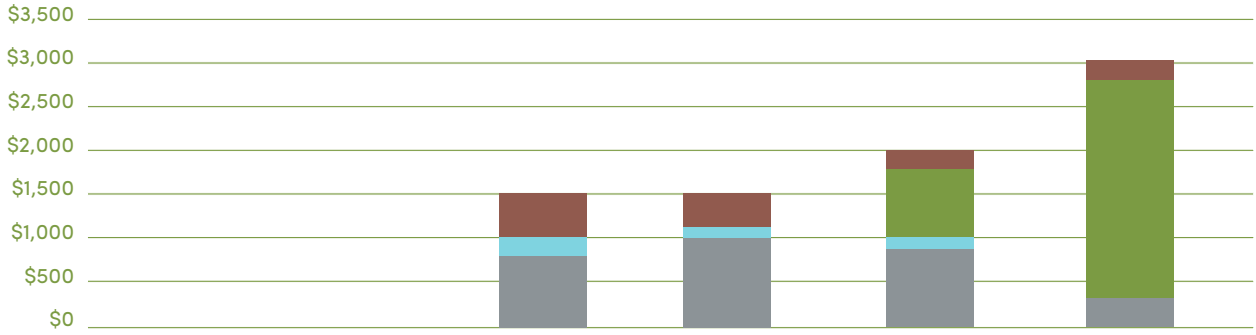
- Cost of installation of an AC refrigerator is included in the capital cost, as it is sold as a play and plug unit
- TCO of AC refrigerator on diesel generators does not include capital cost or maintenance costs of the diesel generator system
- Average cost of energy depends on the cost of grid electricity and cost of diesel
- Solar with battery system and grid connectivity has smaller solar array and lower battery capacity considering compatibility with grid

[120] Note: The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs.

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

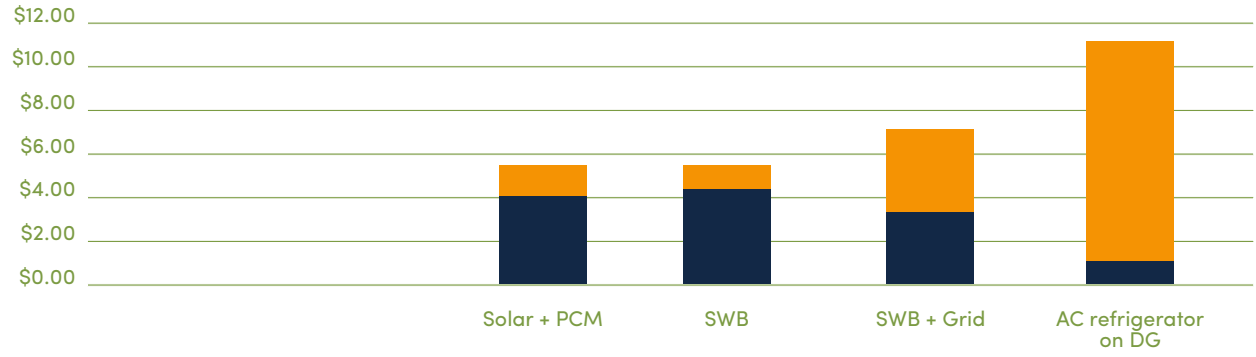
3.3.3 Prevalent Technologies

Figure 27: Total cost of ownership of refrigerators for micro-enterprises over a lifetime period of 10 years



	Solar + PCM	SWB	SWB + Grid	AC refrigerator on DG
Average Cost of Maintenance over lifetime	$400	$333	$227	$67
Average Cost of energy over lifetime	$0	$0	$728	$2,625
Average Cost of Installation	$133	$133	$133	$0
Cost Price of the Product (size-268L)	$933	$1,025	$759	$307

Figure 28: Average cost per litre over a lifetime period of 10 years of refrigerator for micro-enterprises



	Solar + PCM	SWB	SWB + Grid	AC refrigerator on DG
Average OPEX over lifetime per Litre	$1.49	$1.24	$3.56	$10.04
Average CAPEX per Litre	$3.98	$4.32	$3.33	$1.14

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.3.3 Prevalent Technologies

Box 5: Case study on last mile distribution model for off-grid solar refrigerator in micro-enterprises[121]

BOOND Engineering & Development (a private solar company) partnered with Aajeevika Bureau (NGO) to install off-grid solar refrigerators at petty shops (for storage of cold drinks, vegetables, milk, curd and other perishables) in Rajasthan.

They installed refrigerators based on solar PV with battery (panel 300 Wp, battery 200 Ah, 12 V/40A charge controller) technology at these shops. The installation of off-grid solar refrigerators led to an increase in income of petty shop owners by USD 30-USD 40 during the summer months. This technology directly benefitted more than 100 families in rural areas.

3.3.4 Challenges and Opportunities

Companies and consumers face similar challenges in both the household and micro-enterprise segments. These include high upfront costs of technology (2-3 times of grid-connectedAC refrigerators), limited options for consumer financing, and poor access to commercial finance for companies to scale up their business. Another major challenge is inadequate after sales service, due to the remote and scattered customer locations. This is crucial to attain higher customer satisfaction. Moreover, a lack of skilled labour and limited technical capability among retailers and distributors makes provision of after-sales services difficult.

Companies can target large retail shops and micro-food processing industries that require refrigeration for cooling produce and storing perishable items in areas with irregular supply of grid electricity. Demand from the micro-enterprise segment is expected to increase during the summer season. Off-grid solar refrigeration is a cost effective and energy efficient solution to supply rural areas with necessary refrigeration requirements. The MNRE scheme on 'Scale up of Access to Clean Energy for Rural Productive Use' provides an opportunity for companies to improve the market penetration of renewable energy technologies including solar-powered cold storage. Companies can integrate refrigeration technology with other products such as mini-grids. This will offer a potential solution for meeting demands in completely off-grid areas.

© Phocos

[121] GIZ-SELCO Innovation and Replication: Case Studies; June 2015 (Link)

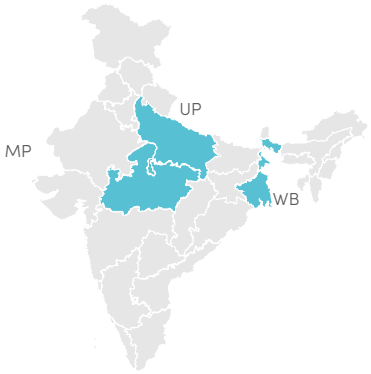
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4 Farm-Gate (Fruits and Vegetables)

3.4.1 Market Size and Need Assessment

India has a total addressable market of USD 15 billion for off-grid solar refrigerators, to store perishable fruits and vegetables at the farm-gate level.[122] As per the Economic Survey of 2019-20, the agriculture sector contributed to 16.5% of the total gross value added (GVA) of the economy.[123] Over the years, India has witnessed a marked increase in the consumption of perishable produce, especially fruits and vegetables. In 2018-19, the total production of fruits and vegetables was 284 million MT.[124] More than 50% of fruit and vegetable production is concentrated in the five states of Uttar Pradesh, West Bengal, Madhya Pradesh, Andhra Pradesh and Maharashtra. However, the demand supply mismatch and inadequacy of appropriate farm-to-market logistics and infrastructure contributes to high food losses, especially in the case of perishable products. This results in widespread price fluctuations and inflationary pressures. The estimated post-harvest losses of fruits and vegetables due to poor refrigeration facilities are USD 8.4 billion per annum in India.[125] Annually, 16% of perishable fruits and vegetables are wasted due to improper refrigeration facilities.[126] In 2018-19, this amounted to a wastage of 5.6 million MT of highly perishable fruits and vegetables which require refrigeration in the range of 0°C to 10°C. According to stakeholders, owing to increased demand in this sector, the segmented market size of farm-gate off-grid solar refrigerators is estimated to be USD 3.7 billion with an adoption rate of around 25%.

Figure 29: Potential states for off-grid solar refrigerators at the farm-gate



The states of Uttar Pradesh, West Bengal and Madhya Pradesh have the greatest potential of piloting off-grid solar refrigerators at the farm-gate level. These are the top three states with the highest deficit in refrigeration capacity among the states with maximum fruit and vegetable production. The two parameters considered for the selection of these states are (i) production of fruits and vegetables, and (ii) installed capacity of cold storage units in India. Majority of the existing refrigeration units are used for a single commodity, which highlights the need to install smaller capacity units for multi-commodity usage. Most companies (such as Ecozen, Promethean Power, Inficold, Tan90, PLUSS) are providing solar refrigeration solutions for farmers. Development partners such as GIZ and SELCO foundation are also aiding companies/customers for implementation off-grid solar refrigerators at the farm-gate level.

Table 5: Production of Fruits and Vegetables that require chilling at 0°C to 10°C (2018-19)

Fruits and Vegetables (chill at 0°C to 10°C)	Production ('000 MT)
Strawberries	5
Kiwi	13
Carrots	1,865
Apples	2,503
Grapes	2,958
Oranges	3,401
Okra	6,170
Cabbage	9,095
Cauliflower	9,103

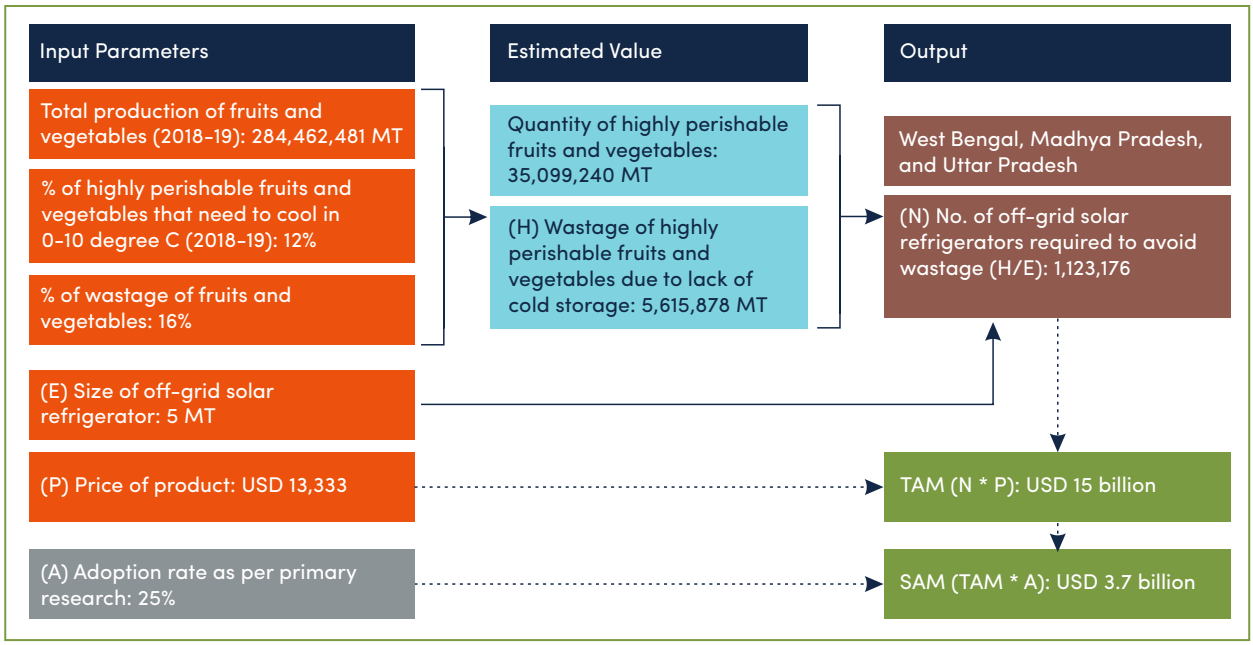
[122] Intellecap Analysis
[123] Web Article – Report Summary of the Economic Survey 2019-20; PRS India; (Link)
[124] Area and Production of Horticulture Crops 3rd Advance Estimate; Ministry of Agriculture and Family Welfare (Link)
[125] Ibid
[126] Web Article - India wastes up to 16% of its agricultural produce; fruits, vegetables squandered the most; Financial Express; July 2019 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4.1 Market Size and Need Assessment

There is a need to establish small size off-grid solar refrigerators at the farm-gate level to enable smallholder farmers to store their produce. Currently, India has 8,186 on-grid/diesel refrigerators, with a total capacity of 37.42 million MT.[127] About 55% of the total on-grid/diesel refrigeration systems capacity is concentrated in the states of Uttar Pradesh and West Bengal only. The typical capacity of these cold storage units is 5000 MT. These are designed for long term storage of bulk produce. Due to the differing temperature requirements per product, it is not possible to store multiple produce. Around 75% of the total on-grid/diesel refrigeration systems in India are single commodity (mainly potatoes) and only 25% are multi-commodity cold storages. The other cold storage facilities are mostly used for tomatoes and onions. In 2018-19, 35.1 million MT of the highly perishable fruits and vegetables (~12% of total fruits and vegetables) required refrigeration in the range of 0°C to 10°C.[128] The production of these fruits and vegetables is given in Table 5. The majority of this produce has a short shelf-life and requires low-cost small-capacity refrigeration units for preservation. According to stakeholders, off-grid solar refrigerators of 5 MT capacity at the farm-gate can enable farmers to store and supply their produce to the market at an appropriate time. These off-grid solar refrigerators can also store fruits and vegetables with variable temperatures. Companies like Ecozen and Pluss Advanced Technologies are providing efficient farm gate off-grid solar refrigerators in this market segment.[129] [130] Figure 30 illustrates the methodology and assumptions for calculating the market size for off-grid solar refrigerators for the farm-gate segment.

Figure 31: Calculation of market size for off-grid solar refrigerators for the farm-gate segment



[127] Press Release on Cold Storage Facilities in the Country for Storing Perishable Horticulture Produce; GoI; Sep 2020 (Link)
[128] All India Cold-chain Infrastructure Capacity Assessment of Status and Gap; National Centre for Cold-chain Development; 2015 (Link)
[129] Website – Ecozen (Link)
[130] Website – Pluss Advanced Technologies (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

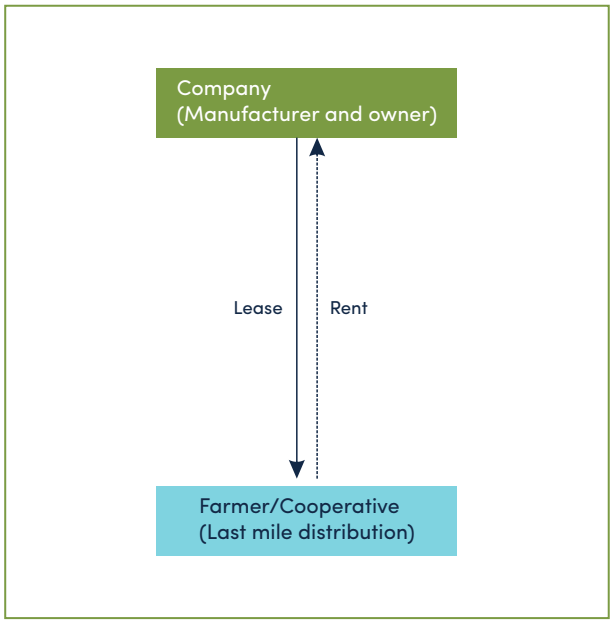
3.4.1 Market Size and Need Assessment

Off-grid solar refrigerators can help farmers avoid distress sales and improve income. Proper refrigeration enhances farmer incomes by reducing the post-harvest losses as well as allowing farmers to store produce for sale at better market prices. Off-grid solar refrigerators at the farm-gate level can be primarily used for storing highly perishable fruits and vegetables for shorter durations (around 1 to 4 weeks). This enables farmers to bargain for a better price for their produce at the regular bi-weekly/weekly wholesale markets. For example, in Jharkhand, farmers accrued an additional profit of USD 27 to 40 per MT by delaying the selling of highly perishable items by two days. Furthermore, this leads to a reduction of post-harvest losses, thereby increasing the market share of the farmer. For example, in Maharashtra, after installing off-grid solar refrigerators of 5 MT, farmers noticed a decline in their post-harvest losses from 15% to 2%.[131]

3.4.2 Business Models

With an adoption rate of around 25%, lease/rent models and community owned models are the most favourable business models for off-grid refrigeration systems. In the lease/rent model, the renter pays a fixed monthly rent to the system owners. The owners of the systems can be an FPO (farmer producer organisation) or a village level entrepreneur. Some companies have enabled a digital payment mechanism to ensure the timely receipt of payments and remote monitoring. The lease or rental charges are flexible across produce and geography. For example, Ecozen provides a portable 5 MT cold storage on rent to a group of farmers and FPOs. This is being commonly used to store highly perishable fruits and vegetables. Some farmers also store flowers and exotic fruits and vegetables. The rental amount varies according to the produce and its temperature requirements.

Figure 31: Rental/Lease model for installation of refrigeration facilities at the farm-gate



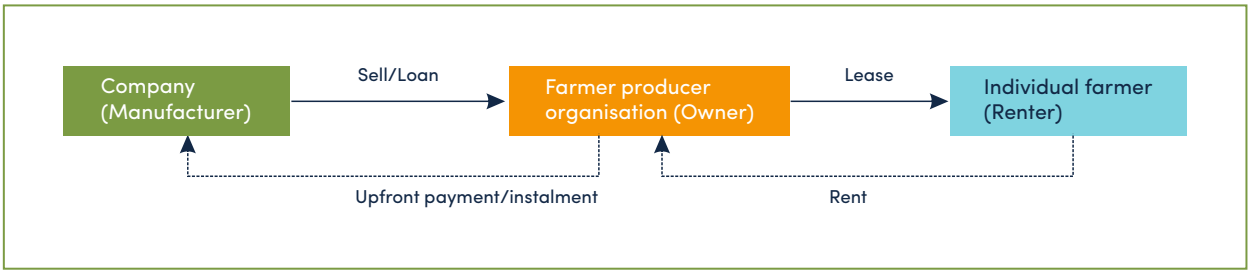
In the community-based business model, FPOs can either retain the ownership of the cold storage or give it on rent to their members. In this business model, the FPO manages the facility and charges each farmer for usage of storage based on type, quantity and period of storage. This model has been termed Cooling as a Service (CaaS). For example, an FPO (of fruit producers) charges a wholesaler approximately USD 167/year/ton as rent for storing produce in its cold storage unit. The FPOs need to show a healthy balance sheet and prove its creditworthiness to the financial institutions to get a loan for setting up the off-grid cold storage. Along similar lines, an innovative model could be pay-as-you-use, where farmers pay only for the storage period of the produce. This business model can keep off-grid cold storage operational throughout the year, leading to efficient capacity utilisation. This also helps improve livelihoods for smallholder farmers and small traders by reducing post-harvest loss of high value crop, and increasing profits through greater bargaining power at the marketplace.

[131] Web Article - Solar-powered cold room boosts farm incomes; India Climate Dialogue; May 2018 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4.2 Business Models

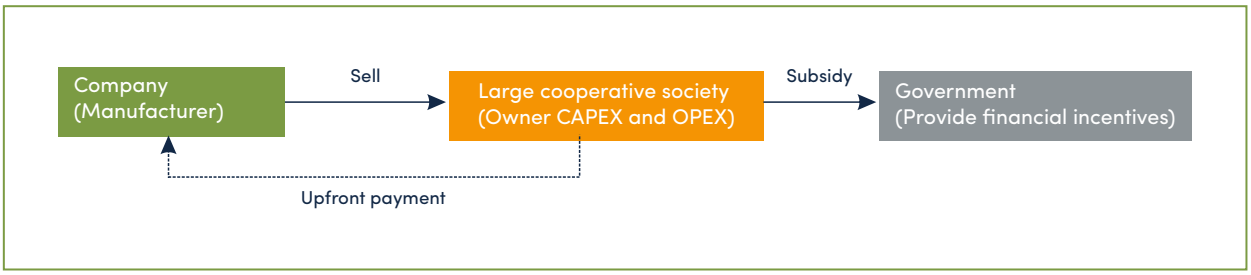
Figure 32: Community based business model for the farm-gate segment



The three business models mentioned above are most preferred by small holder farmers, as they do not incur a high upfront capital cost. They allow farmers to use storage services based on their need and cash flow. Companies offering off-grid solar refrigeration can incorporate similar business models to enter the market.

The upfront purchase business model is the most common business model for cooperative societies as they prefer retaining ownership over the assets. It is, however, not viable for small holder farmers due to the high capital expenditure requirements. This model is highly dependent on viability gap funding or subsidy support from government or NGOs. The majority of the companies prefer this model because the payment risk is lower compared to the lease/rent model or CaaS model. Companies receive the entire payment upfront and they do not have to rely on payment instalments and/or its recovery.

Figure 33: Upfront purchase of refrigerators in the farm-gate segment



Box 6: Case study on benefits accrued to Kenyan agribusinesses through off-grid solar refrigerators[132]

The implementation of farm-gate off-grid solar refrigerators allows agri-businesses to reduce the number of intermediaries (such as warehousing and logistics) and enable direct purchase from the farmers. This has led to better price realisation for farmers. This also provides incentives to farmers to improve the quality of their produce. The price differential between the refrigeration market and the informal domestic market can be as high as 50%. For example, the price of fresh beans in the informal domestic market is USD 0.18-USD 0.28/kg, which can increase to USD 0.51-USD 0.60 /kg in the cold chain market during the same week of sale.

[132] Web Article – The Cold Chain Opportunity: Reducing Post-harvest Losses and Increasing Market Access for Rural Farmers; Shell Foundation (Link)

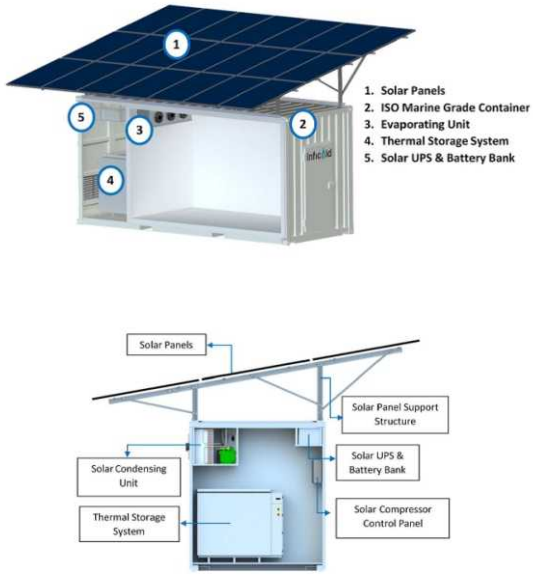
3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4.3 Prevalent Technologies

The most viable technology application is Solar PV with PCM thermal battery considering cost-economics. It has the lowest TCO of ~USD 39,070 over a lifetime period of 10 years.[133] The electric energy generated by solar PV panels directly powers a variable speed compressor. These compressors use eco-friendly refrigerants. The compressor generates cooling with the help of PCM material (water/ice), which is stored inside the PCM thermal batteries. When solar energy is low or not available, cooling in the cold storage is provided by the PCM thermal batteries. Most commonly, companies use PCM material plates and PCM materials lines inside the container to make the system more efficient.

Solar PV with battery systems is the most widely used technology as it enables continuous cooling for fruits and vegetables, compared to the existing grid connected refrigerators in weak-grid areas. This technology uses electrochemical batteries for storing the energy. The energy from solar panels mounted on the rooftop of the cold room is stored in high capacity batteries. These batteries power the inverter, which in turn supplies power to the refrigerating unit and keeps the system operational in the absence of solar energy. Figure 34 shows the major components of the farm gate off-grid solar refrigerators. The operating temperature range of these refrigerators is 3°C to 20°C. A user can configure its temperature through a control panel. The system also has a provision for creating two different temperature zones within the same cold storage unit. This is a useful feature to store different commodities at their ideal storage temperature conditions, and extend their shelf life. The estimated TCO of this technology is ~USD 44,300 over a lifetime period of 10 years.[134] The other common technology is solar PV, which operates on a grid connection and diesel generator with a TCO of ~USD 59,800 over a lifetime period of 10 years. The operating expenses over a lifetime period of the off-grid refrigeration unit dependent on grid and diesel generator is ~USD 9,200 per MT compared to ~USD 4,200 per MT for a solar PV with battery system. This is mainly due to the high energy cost pertaining to diesel consumption.

Figure 34: Solar PV with battery system for farm-gate refrigerator



In this segment, some companies are also innovating with biomass-based refrigeration due to ready availability of biomass from degraded fruits and vegetables. Biomass-based refrigerators effectively utilise the waste heat coming from the exhaust of a biomass gasifier that is otherwise lost into the air. This arrangement operates the cold storage unit with minimal thermal wastage. The cold storage unit is an ammonia-based system that runs on a vapour adsorption cycle. Ammonia in vaporised form, running through an evaporator, is used to cool a 'cold room' for the requisite storage capacity.[135] The estimated TCO over a lifetime period of 10 years for a 5 MT solar PV and biomass system is ~USD 47,000. Figure 35 and 36 below highlight the TCO of various technologies such as solar with PCM thermal battery, solar with battery, biomass-based systems and systems that runs on diesel generators.

[133] Note: The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs
[134] The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs
[135] Biomass Based Sorption Cooling Systems for Cold Storage Applications; International Journal of Green Energy; October 2005 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4.3 Prevalent Technologies

Note: Specific assumptions for estimation of TCO

- TCO of AC refrigerator on diesel generators does not include capital cost or maintenance costs of the diesel generator system
- Average cost of energy depends on the cost of grid electricity and cost of diesel
- Solar refrigerator which operates on a grid connection and diesel generator has smaller solar array and lower battery capacity considering compatibility with grid

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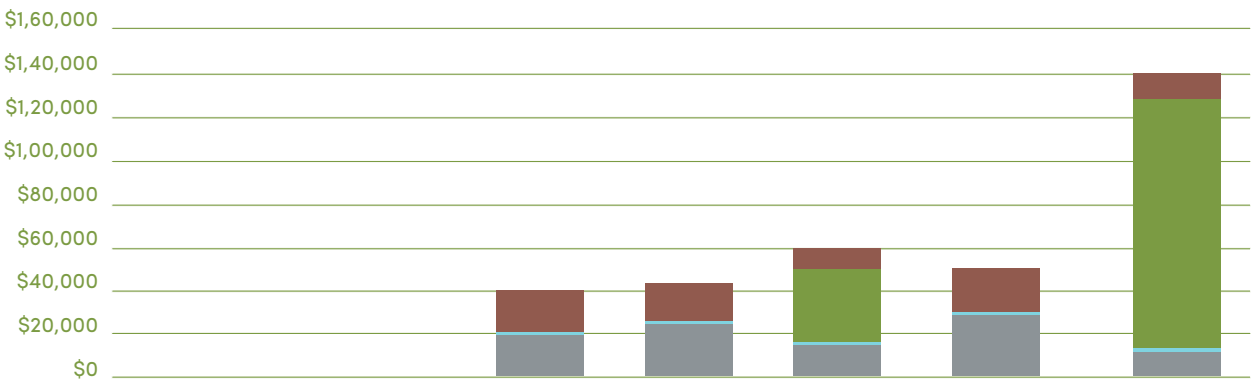
Figure 35: Total cost of ownership over a lifetime period of 10 years of refrigerators for the farm-gate segment

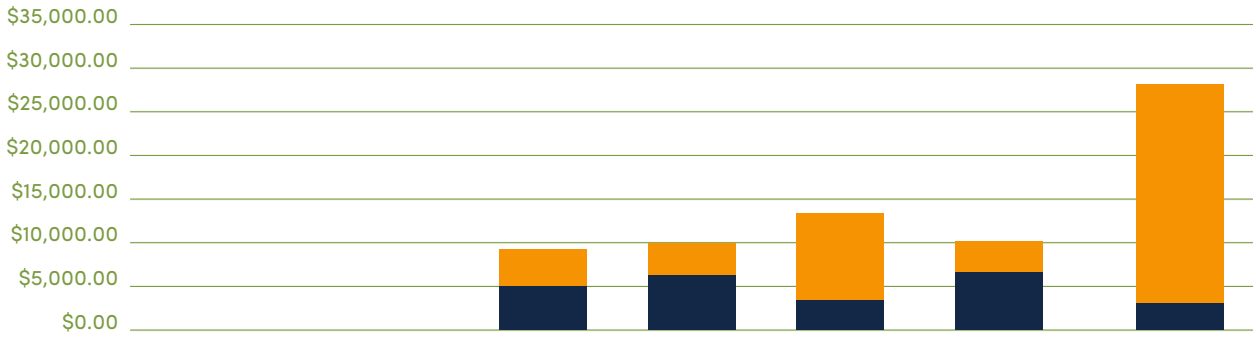


	Solar + PCM	SWB	SWB + DG + Grid	Solar PV + Biomass	AC refrigerator on DG
Average Cost of Maintenance over lifetime	$20,000	$21,067	$13,333	$20,000	$13,333
Average Cost of energy over lifetime	$0	$0	$32,736	$0	$1,22,496
Average Cost of Installation	$400	$400	$400	$533	$400
Cost Price of the Product (size-5MT)	$18,667	$22,813	$13,333	$26,667	$9,333

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4.3 Prevalent Technologies

Figure 36: Average total cost per ton over a lifetime period of 10 years for refrigerators in the farm-gate segment



	Solar + PCM	SWB	SWB + DG + Grid	Solar PV + Biomass	AC refrigerator on DG
Average OPEX over lifetime per MT	$4,000.00	$4,213.33	$9,231.87	$4,000.00	$27,165.87
Average CAPEX per MT	$3,813.33	$4,642.67	$2,746.67	$5,440.00	$1,946.67

Box 7: Case study on donor supported off-grid solar refrigerators[136]

The United Nations Development program (UNDP) installed off-grid solar refrigerators at the farm-gate to improve livelihoods of small holder farmers in the Koderma district of Jharkhand. These refrigerators are based on solar PV and PCM technology. The 'micro' refrigeration units (sized 20×8×8ft) are powered by a 4 kWp solar PV systems to operate the refrigeration system (battery-less compressor operation) during the day. The unit also includes an innovative thermal storage facility for backup (~24-30 hrs) during non-sunny hours. The unit is designed to maintain temperature in the range of 2-10^{0}C and relative humidity in the 80-95% range.

Intelligent control architecture is integrated in the system for temperature and humidity management based on the quantity and type of fruits and /or vegetables stored. In addition, a remote monitoring system is also provided as a protective maintenance option to avoid down time. The system is a hybrid system compatible with the grid (single and three phase) as well as with a generator. These off-grid solar refrigerators are being operated and managed by local FPOs. The FPO earns revenue by charging farmers for storage of their produce based on type, quantity and period of storage. The payback period on the investment for the FPO is ~2 years. The off-grid solar refrigerators have helped 283 beneficiary farmers to avoid distress sales and earn higher incomes.

[136] Primary research

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.4.4 Challenges and Opportunities

Small holder farmers have not adopted farm-gate off-grid solar refrigerators due to the high upfront cost of the technology and low awareness on usage of technology. Low purchasing power of the farmers and poor access to formal sources of financing limits the uptake of newer technologies. One of the key reasons for limited consumer financing is lack of understanding of technologies and business cases by financial institutions. Financial institutions have attached high risks to this technology due to an absence of demonstrated bankable business cases. There is limited information on the technology and economics of the product (return on investment, payback period, etc.) available within financial institutions. Hence, financing for the farm-gate off-grid solar refrigerator is restricted. Another challenge impeding market development is the lack of off-grid cold storage units with temperature variability. In most parts of India, many cold storage units support only a single commodity – usually the potato. However, fruits and vegetables require different temperatures for maintaining quality. Limited knowledge among companies on temperature requirements and allied technologies makes it difficult for farmers to adopt new technologies.

Recent policy developments are providing support to entrepreneurs to develop opportunities in the farm-gate off-grid solar refrigerator sector. The Ministry of Agriculture and Farmers Welfare and government agencies like the National Bank for Agriculture and Rural Development (NABARD) are supporting the farm-gate refrigeration sector by providing funds at low interest rate rates to companies and consumers. The government also launched a USD 66 million scheme, 'Operation Greens', to promote the integrated development of cold chain for all products, shifting from TOP (Tomato Onion Potato) to TOTAL (all fruits and vegetables) for a pilot period of 6 months. Additionally, the government announced a USD 13.3 billion Agriculture Infrastructure Fund,[137] a part of which will be dedicated to refrigeration and post-harvest management of agriculture produce (detailed in Chapter 4 of the report). Furthermore, linking agriculture supply chains with refrigeration, and providing cooling as a service, is a big opportunity for companies.

© Ecozen

[137] Financing facility under 'Agriculture Infrastructure Fund': Scheme Guidelines; Ministry of Agriculture and Farmers' Welfare; GoI; 2020 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

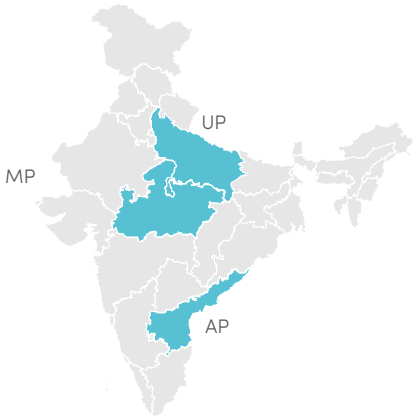
3.5 Dairy (Milk)

3.5.1 Market Size and Need Assessment

The total addressable market for off-grid solar refrigeration in the dairy segment is USD 164 million.[138] India is the largest milk producing country (~21% of global market share) in the world with substantial requirements for on-site refrigeration. Thus, for the dairy segment, we have only considered the potential market for off-grid solar milk chillers. According to Rogers's bell curve, the segmented addressable market is USD 16 million with an adoption rate of 10%.[139] In 2018-19, the total milk production in the country amounted to 187 million tonnes.[140] The states with the highest milk production capacity were Uttar Pradesh (16%), Rajasthan (13%), Madhya Pradesh (8%), Andhra Pradesh (8%) and Gujarat (8%). Out of the total milk production in the country, about 48% of milk is either consumed at the producer level or sold to consumers in the rural areas. The remaining 52% of the milk is available for sale to consumers in urban areas. It is estimated that only about 40% of this supply, which reaches urban areas, is handled by the organised sector. As of March 2019, there were 17 million dairy farmers registered across 1,90,516 village-level dairy cooperative societies (DCS).[141] On average, dairy farmers produce 30 litres of milk per day. To avoid bacterial growth, substantial cooling facilities are required.

Andhra Pradesh, Uttar Pradesh and Madhya Pradesh are among the top milk producing states in India, with low volume of milk chilling capacity.[142] These highest potential states can be targeted for piloting off-grid solar milk chillers. These three states have been selected based on a ranking system of all states, which considered two main parameters: (i) production of milk and (ii) capacity of chilling centres and bulk milk coolers. These states can be considered for immediate market entry. There are already some companies who are piloting off-grid solar chilling units in these states. For example, Inficold plans to demonstrate a retrofittable instant milk chilling system operating on thermal energy in the state of Uttar Pradesh.[143] Promethean Power Systems has also installed PCM thermal battery based refrigeration units in the states of Uttar Pradesh, Andhra Pradesh, Maharashtra and Tamil Nadu.[144]

Figure 37: Potential states for off-grid solar milk chillers



© Inficold

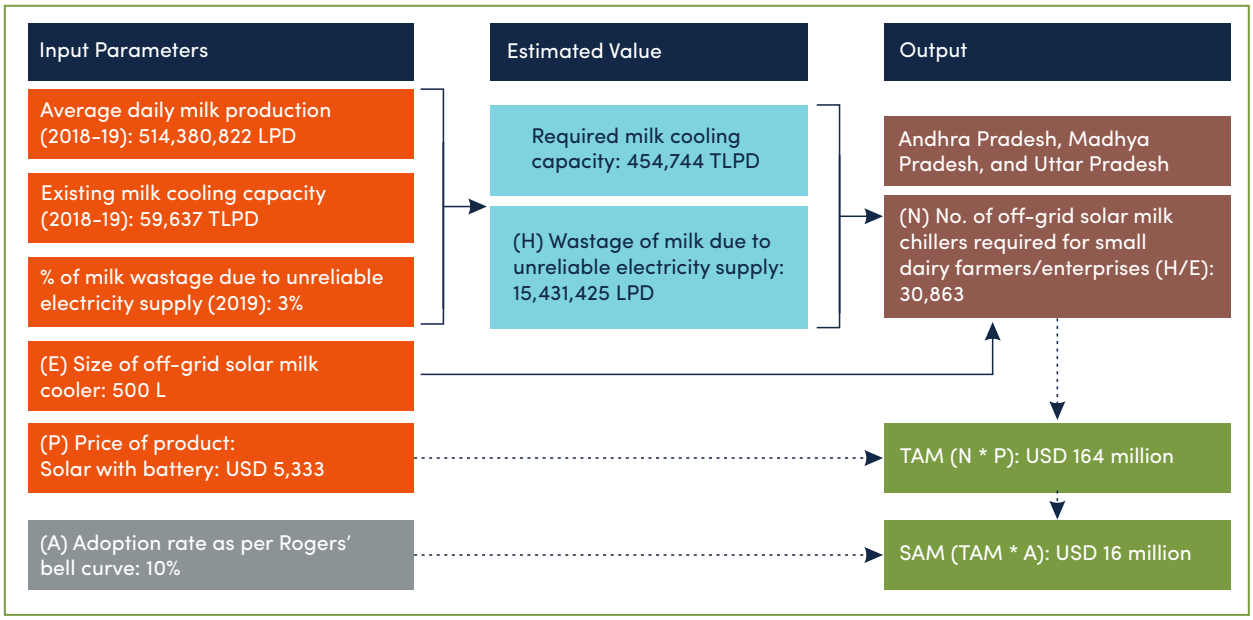
[138] Intellecpa Analysis
[139] Note: The Rogers Bell Curve classifies users for the adoption or acceptance of a new product or innovation into various categories, based on their willingness to accept new technology or an idea
[140] Basic Animal Husbandry Statistics 2019; Ministry of Fisheries, Animal Husbandry, and Dairying; GoI (Link)
[141] Annual Report 2018-19; National Dairy Development Board (Link)
[142] Basic Animal Husbandry Statistics 2019; Ministry of Fisheries, Animal Husbandry, and Dairying; GoI (Link)
[143] Innovation by Inficold; Facility for Low Carbon Technology Development; UNIDO (Link)
[144] Web Article - Promethean Power Systems is revitalizing dairy farming industry; Economic Times; February 2017 (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.5.1 Market Size and Need Assessment

To provide refrigeration, off-grid dairy farmers have to depend on a diesel generator, which makes the cooling process expensive. Hence, there is a huge market for off-grid solar milk chillers in rural areas.[145] Milk chillers are used to cool the milk from its harvest temperature of 35°C to 4°C, and arrest the bacterial growth. This maintains the quality of harvested milk. Milk can be used for seven days by avoiding deterioration and bacterial growth if it is cooled on the site of harvesting at the right temperature. Currently, bulk milk coolers dominate the cooling market with a share of 67%, followed by milk chilling centres (33%). In 2018-19, the total capacity of bulk milk coolers was 41,447 thousand litres per day (TLPD), while that of milk chilling centres was 18,190 TLPD.[146] In India, the average daily milk production is 0.51 million tonnes per day whereas the milk cooling capacity is only 0.060 million tonnes per day (of chilling centres and bulk milk chillers). This amounts to ~12% of the total milk production capacity. Annually, at least 3% (15.4 million litres per day) of the total milk produced gets wasted due to unreliable and erratic electricity supply.[147] Milk needs to be cooled at the source to increase its shelf life and avoid the estimated loss of ~USD 6 million per day (considering an average price of ~USD 0.39 per litre in India). As of now, the majority of dairy farmers are using diesel generators as back-up systems. These diesel generators have significant cost implications due to high energy costs. However, off-grid solar milk refrigerators remove these operating cost concerns for storing milk. Currently, on-site off-grid solar milk chillers with capacities in the range of 150–500 litres are available in the market. According to stakeholders, off-grid solar milk chillers with a capacity of 500-litres can enable a group of 15 dairy farmers to store milk efficiently. Companies like Inficold and Promethean Power Systems are providing efficient off-grid solar milk chillers in this market segment.[148][149] Figure 38 illustrates the methodology and assumption for calculating the market size for off-grid solar milk chillers.

Figure 38: Calculation of market size for off-grid solar milk chillers



[145] Web Article - Solar cold storage and other solutions preventing milk wastage in India; Financial Express; November 2019 (Link)
[146] Annual Report 2018-19; National Dairy Development Board (Link)
[147] Web Article - Solar cold storage and other solutions preventing milk wastage in India; Financial Express; November 2019 (Link)
[148] Website – Inficold (Link)
[149] Website – Promethean Power Systems Limited (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.5.1 Market Size and Need Assessment

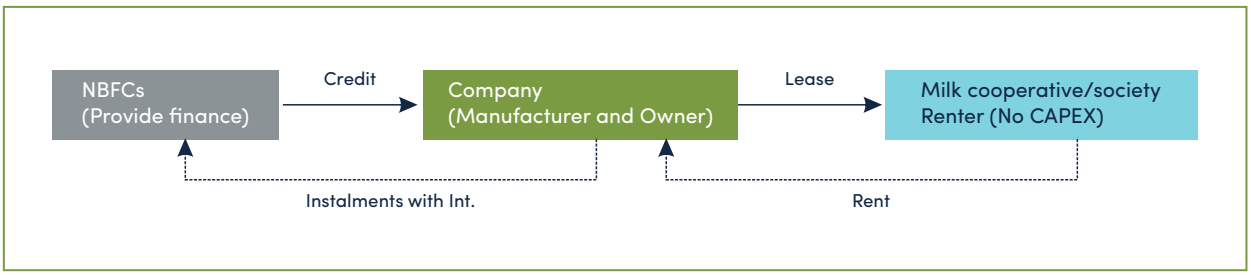
Off-grid solar refrigerators have a huge market potential with a year-on-year increasing milk processing capacity in India. Between 2018 and 2023, the milk processing industry is projected to grow at a compound annual growth rate (CAGR) of 14.8% to reach ~USD 38 billion in 2023.[150] A larger share of dairy farmers is expected to move towards producing value-added products (such as curd and cheese, etc.) in the near future. Even smaller dairy farmers in rural areas have started aggregating as cooperatives to create value-added products and generate higher incomes. However, a lack of sufficient refrigeration facilities may hamper the growth of this sector. This is specifically a challenge for the unorganised sector which comprised ~81% of market share in 2018-2019.[151] Thus, this is another potential market opportunity that can be explored by companies manufacturing for off-grid solar refrigerators.

3.5.2 Business Models

The lease or rental model is the most promising business model for off-grid milk refrigeration, as majority of dairy farmers may not have the capacity to purchase off-grid solar milk chillers. This is due to the high upfront payment requirements. Promethean Energy operates a build-own-transfer (BOT) model. It creates assets of milk chillers with support from Non-Banking Financial Corporations (NBFCs) and provides on-site milk chillers to the milk cooperatives/societies (i.e. the customers).[152] Promethean Energy receives rent from consumers on a monthly basis. Once the definitive cost according to the service level agreement (SLA) is recovered, the milk chiller is transferred to the milk cooperative society. The NBFCs usually have a line of credit linked to the receivables to secure the payment. In this business model, the creditworthiness and payment ability of the customer are the major considerations. This model enables risk sharing that balances risk of payment and technology for the company and the customer.

Direct sales with and without support of government subsidies is another business model that dominates the on-site, off-grid solar milk chillers market. In this business model, companies receive an upfront payment from customers, while the government supports customers with viability gap funding or subsidies. The government deposits the subsidies directly into the customer's account. In the organised dairy sector, the government also provides incentives to cooperative societies to install solar-based milk chillers at the source. To enhance milk refrigeration capacities, the government has provided subsidies to 50 state federations (e.g. Gujarat Cooperative Milk Marketing Federation Ltd), 170 unions at the district level (e.g. Ahmedabad District Co-op Milk Producer's Union Limited), and dairy societies at the village level.

Figure 39: Lease/rental business model for refrigerators in the dairy segment

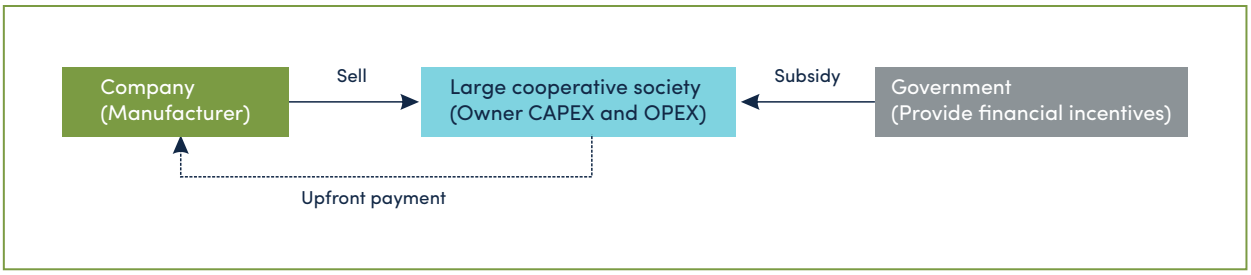


[150] Dairy Industry in India 2020 Edition: Market Size, Growth, Prices, Segments, Cooperatives, Private Dairies, Procurement and Distribution; IMARC Group; 2019 (Link)
[151] Web Article - Dairy & Milk Processing Market in India; Business Wire (Link)
[152] Web Article - Promethean's Rapid Milk Chiller (Link)

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.5.2 Business Models

Figure 40: Business model for upfront purchase of milk chillers enabled by government subsidies



Cooling-as-a-service (CaaS) is also an emerging business model, whereby large private dairies provide CaaS to other milk collection centres during the lean period (from the month of May to October). The big cooperatives/large private dairies (the 'owners') purchase the technology from companies by making an upfront payment. The owners then provide storage and chilling of milk on a pay-as-per-use basis to small milk dairies/societies. The risk of payment recovery in this model lies with the owners. However, this is not a major challenge considering the long-term relationships between owners and small milk dairies/societies. For example, Chitale Dairy in Maharashtra helps village level milk societies with milk cooling at their own chilling unit.

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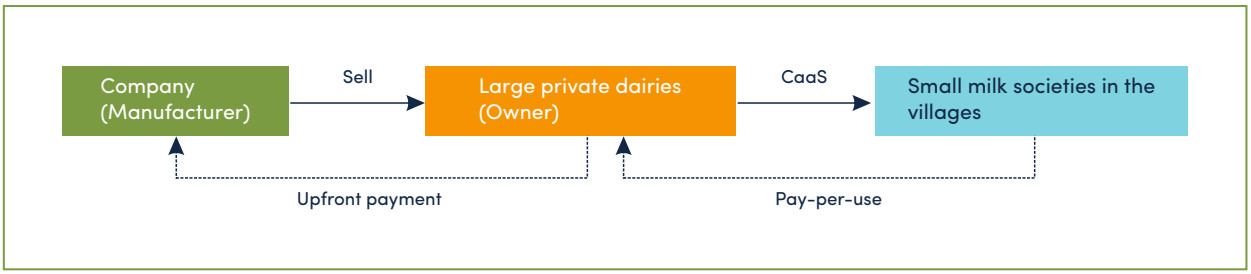
Figure 41: Cooling-as-a-service (CaaS) business model by large private dairies in the dairy segment



3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.5.2 Business Models

Box 8: Case study on Dairy Business Hub Model in Kenya[153]

Under the East African Dairy Development programme, a dairy producer company (Metkei Multipurpose Company) was established to help dairy farmers achieve economies of scale. It enabled centralised collection, chilling and marketing. This is a dairy business hub model. It was implemented in Keiyo South District of Kenya.

The dairy producers' company was funded by capital contributions from 5,540 small-scale dairy farmers. The company sells ~20,000 kgs of milk per day on behalf of its members. This has increased milk pay-outs for these dairy farmers by at least USD 0.16 per litre. The model also helped boost private public partnership in the milk supply chain sector, thereby resulting in improved milk quality and better pricing for small-scale dairy farmers.

3.5.3 Prevalent Technologies

Solar PV with PCM thermal battery, along with solar PV with battery technology, can be a transformational technology in the milk off-grid refrigeration sector. A solar PV with PCM thermal battery system to cool 500-litres of milk requires 5.2 kWp of solar panels and thermal batteries.[154] On-site, off-grid solar milk chillers are powered by solar PV, which store energy in thermal batteries for cooling during non-solar hours. This system provides the most affordable and reliable cooling backup for bulk milk coolers. Thermal batteries can store cooling energy in the form of ice, paraffin or organic PCM material, amongst others. The TCO over a lifetime period of 10 years of a 500-litre capacity off-grid solar milk chiller based on solar PV and PCM thermal battery technology is ~USD 6,130. This is marginally cheaper than solar PV with battery technology, which has a TCO of ~USD 6,670.[155] The solar PV with battery technology ensures cooling with the help of stored electrical energy. The solar PV and battery system can be also integrated to existing grid systems. This system can give power for 6 hours (3 hours each in the morning and evening). The batteries used are typically flooded cell, tubular plate lead acid batteries, which last up to 8 years. Its charging system is equipped with a Maximum Power Point Tracking (MPPT) charge controller for optimum use of solar power. In rural areas, at the time of power cuts, the primary source of energy for most off-grid milk chillers is a diesel generator. This is an expensive option. The average operating cost per litre of refrigerator capacity over the useful life of a milk chiller running on a diesel generator is ~USD 52. Solar PV with battery milk chilling system that instantly cools milk from 35°C to 4°C can eliminate the requirement of diesel generators for traditional milk chillers. This provides a more cost-effective way of collecting high quality milk from village level collection centres where grid power is erratic. Figure 43 and 44 below highlight the TCO of various technologies such as solar with PCM thermal battery, and solar with battery and milk chillers that run on diesel generators (specifically for off-grid areas).

Figure 42: Solar with battery milk chiller

Note: Specific assumptions for estimation of TCO

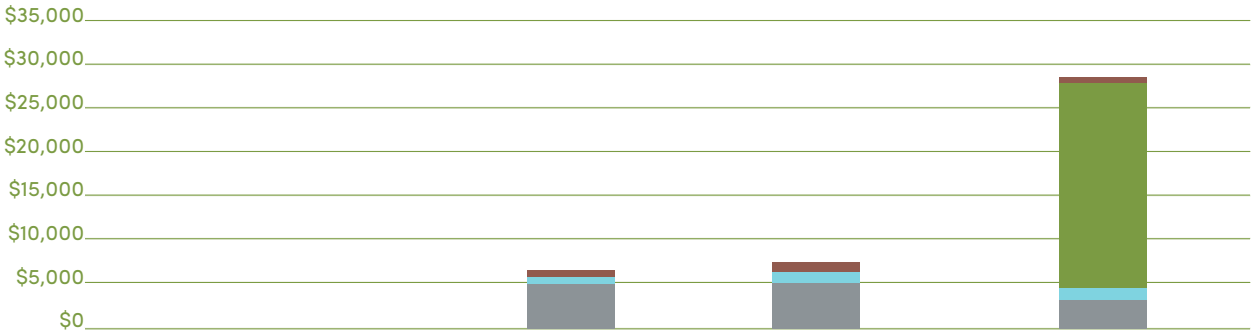
- TCO of a milk chiller on a diesel generator does not include capital cost or maintenance costs of the diesel generator system
- Average cost of energy depends on the cost of diesel

[153] Integrating the Dairy Business Hub Model in a Value Chain Development of Small Holder Dairy Farmers; September 2012 (Link)
[154] Brochure of Inficold (Link)
[155] The numbers have been rounded for ease of reading. The exact numbers for TCO are given in the graphs

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

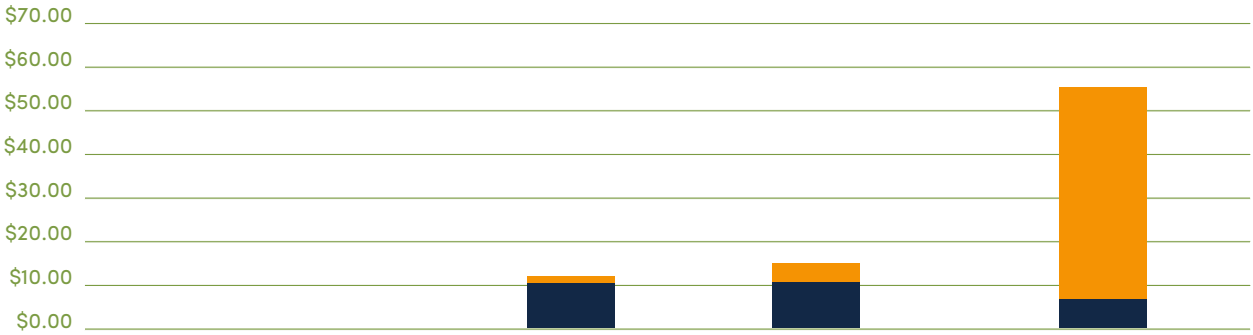
3.5.3 Prevalent Technologies

Figure 43: Total cost of ownership over a lifetime period of 10 years of milk chillers



	Solar + PCM	SWB	Milk Chiller on DG
Average Cost of Maintenance over lifetime	$400	$1,067	$400
Average Cost of energy over lifetime	$0	$0	$25,520
Average Cost of Installation	$267	$267	$267
Cost Price of the Product (size-268L)	$5,467	$5,333	$3,333

Figure 44: Average cost per litre over a lifetime period of 10 years of milk chillers



	Solar + PCM	SWB	Milk Chiller on DG
Average OPEX over lifetime per Litre	$0.80	$2.13	$51.84
Average CAPEX per Litre	$11.47	$11.20	$7.20

3 Market Outlook for Off-Grid Solar Refrigeration Systems in India

3.5.3 Prevalent Technologies

Box 9: Case study on Solar with PCM thermal battery based off-grid solar milk chillers in India[156]

Inficold has installed solar PV with PCM thermal battery based off-grid solar milk chillers at a state cooperative dairy in Sikkim state of India. The Solar PV with PCM thermal storage technology has an effective cooling rate, which can instantaneously reduce the temperature of fresh milk below 7°C. The cold temperature avoids deterioration of milk and prevents bacterial growth, therefore improving the quality of the milk and allowing higher price realisation by the dairy farmer. The cooperative can save up to USD 225 per month by avoiding usage of diesel generators. The payback period for the cooperatives with energy savings is ~2 years.

3.5.4 Challenges and Opportunities

The key challenges pertaining to the dairy segment are the highly unorganised sector and fragmented market. There is poor accountability of milk production and losses due to lack of processes. Furthermore, limited knowledge among dairy farmers about on-site cooling and usage of off-grid solar milk chillers impacts the quality of milk. Access to finance for companies is another major challenge due to lack of a demonstrated bankable business case. The other key challenges like poor consumer financing and affordability of the on-site off-grid solar chillers are also relevant for the dairy segment.

In recent years, focused interventions by the government on the development of refrigeration infrastructure for the dairy segment are providing opportunities to off-grid solar technology players. The government is providing an impetus for refrigeration infrastructure with the USD 2 billion Animal Husbandry Infrastructure Development Fund. This fund aims to support the infrastructure requirements of dairy sector (including milk chillers), thereby increasing interest from cooperative societies for the procurement of milk chillers to maintain milk quality. Companies can leverage the assistance provided under this policy to scale up their technology and increase market penetration. Moreover, small milk chilling centres owned by the Gram Panchayat can be set up at each village with the help of government subsidies. There is also an opportunity for the off-grid solar refrigeration of other dairy products (such as curd and ice cream).

© Inficold

[156] Primary Research

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

The ecosystem players that influence market development for off-grid solar refrigerators through 'push' and 'pull' factors include policy makers, development actors, and financiers. The policy makers include government officials from relevant ministries (such as Ministry of New and Renewable Energy, Ministry of Agriculture and Farmers Welfare, Ministry of Food Processing Industries, and Ministry of Fisheries, Animal Husbandry and Dairying) at the national level and the nodal agencies designated to implement schemes at the state/district level. Government policies are based on 'pull' factors such as regulations on energy efficient appliances, mandates on use of renewable energy sources and quality standardisation/certification that facilitates technology development. 'Push' factors such as subsidies, research and development funds, grant, equity and debt financing provide financial incentives to companies for innovation of new technologies. A combination of policies and programs based on these 'pull' and 'push' factors can generate confidence among companies developing innovative off-grid solar refrigeration technologies.

4.1 Existing Policy Framework in India

In India, the government has a limited number of schemes that promote off-grid solar refrigerators as part of larger programmes. The majority of these schemes implemented by the government at the national and state level give incentives to large-scale cold chain infrastructure development for the agriculture and dairy sectors. In these sectors, the interventions adopted by the government include either guidelines on type and size of equipment, or financial assistance through capital subsidies, interest subventions and concessional (soft) loans. These schemes do not specifically focus on off-grid solar refrigeration; however, they do include additional benefits for the application of alternative technologies (such as solar PV panels, PCM, vapour absorption, or solar thermal systems). Some of the most prominent schemes[157] by the government pertaining to refrigeration include provision for solar-based technology and/or provide direct benefit to entrepreneurs/private companies. These have been briefly described below.

There is only one comprehensive scheme that promotes application of different types of solar-powered technologies (like solar cold storage, solar dryers, solar aerators etc.) for rural productive uses/livelihoods. In 2018, the Ministry of New and Renewable Energy (MNRE) launched the scheme on 'Scale-up of Access to Clean Energy for Rural Productive Use'[158] targeting 30,000 beneficiaries in the states of Assam, Madhya Pradesh and Odisha. It is a two-year scheme (2018-2020) with a total project cost of USD 23.04 million, of which, only 2.5% had been realized by end of 2018. This cost includes a contribution of USD 10 million from MNRE, USD 4 million from GEF, USD 0.80 million from UNDP, and USD 8.23 million from other partners (such as state funds, beneficiaries[159], and Corporate Social Responsibility (CSR) funds). The MNRE provides a subsidy equivalent to 30% of the tender cost or benchmark cost (whichever has lower value) to eligible beneficiaries for the implementation of the renewable energy (RE) technology package. Beneficiaries refer to the persons purchasing RE technology for rural productive uses/livelihoods.

The scheme focuses on four components that include:
(I) developing and demonstrating renewable energy technology packages for rural livelihood (RETPRL) applications,
(ii) creating supply chain linkages for RE technologies and service providers,
(iii) facilitating regulatory and policy support, and
(iv) enabling access to finance for decentralized RE-based livelihood applications.

[157] Note: These are not all schemes related to cold-chain infrastructure development in India. Furthermore, the brief description of the listed schemes only defines the key activities pertaining to off-grid solar refrigeration. It does not describe all the initiatives being undertaken by the government within the purview of that scheme.
[158] Website - Schemes of Ministry of New and Renewable Energy (Link)
[159] Note: Beneficiary contribution refers to the cost accrued by beneficiary for acquiring the asset over and above the subsidy provision in the scheme and any additional financial assistance from other sources. This is not a fixed cost. It is dependent on the amount of financing leveraged from other sources.

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.1 Existing Policy Framework in India

The scheme is executed by the State Renewable Energy Development Agencies (SNA) and State Rural Livelihood Missions (SRLMs) through a tender (open to eligible suppliers). The selected suppliers of RE technology are provided support on business planning, supply chain management, and training/capacity building. It is critical to note that till the end of 2018, the scheme had not made significant progress. This was mainly due to a lack of focus on viable technology applications (e.g. solar cold storage, solar thermal drier etc.), limited understanding on the economic viability of RE technology, and uncertainty because of grid electricity expansion in rural areas.[160]

In the agricultural sector, the Ministry of Agriculture and Farmers Welfare has two ongoing financial assistance schemes targeting cold-chain infrastructure development, which can be leveraged for off-grid solar refrigerators at the farm-gate level. Launched in 2014, the Mission on Integrated Development of Horticulture (MIDH)[161] lays down the guidelines for all financial assistance schemes aimed at the holistic growth of the horticulture sector, including aspects related to technology promotion and integrated post-harvest management, amongst other. The schemes support the establishment of cold storage units,pre-cooling units, and refrigerated transport. The MIDH proposes a credit-linked back ended subsidy at 35% in general areas and 50% in North East states and Hilly States. It also offers additional financing for usage of alternative technologies (like solar PV panels, PCM, vapour absorption, or solar thermal systems). This amounts to 100% of the invoice cost with a ceiling of USD 46,667 per project. The benchmark costs that define the upper limit for cold-chain infrastructure subsidies are given in Table 6. The eligible entities that can seek assistance for cold-chain infrastructure development are individuals, group of farmers/consumers, partnership/ proprietary firms, self-help groups (SHGs), farmer producer organizations (FPOs), companies, corporations, cooperatives, local bodies, state government etc. They can receive a subsidy for cold storage capacities up to 5000 MT under the MIDH subsumed schemes of National Horticulture Mission (NHM) and Horticulture Mission for North East and Himalayan States (HMNEH).[162] The financial outlay of the integrated post-harvest management component defined under the MIDH varies as per the action plans drawn by the state governments.

Table 6: Benchmark cost norms for cold-chain infrastructure under MIDH

Item	Benchmark Cost Norms
Pre-cooling unit	USD 33,333 per unit with capacity of 6 MT
Cold room	USD 20,000 per unit of 30 MT capacity
Cold storage with single temperature and large chamber (>250 MT)	USD 106 per MT maximum up to 5,000 MT
Cold storage with multiple temperature	USD 133 per MT maximum up to 5,000 MT
Refrigerated vehicle	USD 34,667 for 9 MT and pro-rata basis for lesser capacity (>4 MT)

[160] Mid-Term Review of Scale-up of Access to Clean Energy for Rural Productive Uses (India ACE GEF Project); MNRE; July 2019 (Link)
[161] Mission for Integrated Development of Horticulture: Operational Guidelines (Link)
[162] Website - Mission for Integrated Development of Horticulture (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.1 Existing Policy Framework in India

The USD 13.3 billion Agriculture Infrastructure Fund (AIF) enables the provision of concessional loans for infrastructure development (including cold storage), through an interest subvention scheme.

This debt financing facility provides loans via banks with an interest subvention of 3% p.a., up to a limit of USD 0.27 million per project. This is applicable for a maximum period of 7 years, with a moratorium for repayment from 6 months to 2 years. Furthermore, additional credit guarantees are available under the Credit Guarantee Fund Trust for Micro and Small Enterprises (CGTMSE) scheme and FPO promotion scheme.

The fund is being administered by the Department of Agriculture Cooperation and Family Welfare (DAC&FW) and NABARD. Some of the eligible entities under this scheme are farmers, primary agricultural credit societies (PACS), SHGs, FPOs, agri-entrepreneurs, start-ups, central/state government agencies, and private-public-partnership (PPP) projects sponsored by local bodies. However, the share of financing for entrepreneurs can be fixed by the government. To reduce post-harvest losses, the guidelines[163] emphasise the promotion of modern cold chain storage systems and innovative agriculture technologies (like artificial intelligence, internet of things etc.). This opportunity can be leveraged by companies developing off-grid solar refrigerators that want to scale-up. The government has sanctioned USD 1.3 billion for the first year of operation (2020-21) and USD 4 billion each for the subsequent three years. As of August 2020, USD 133 million has been dispersed to 2,280 farmer societies.[164]

The Ministry of Food Processing Industries (MoFPI) also promotes farm-level cold storage through project-based financing, including an additional benefit for application of solar-based technology. Since 2008, the scheme on 'Integrated Cold Chain and Value Addition Infrastructure'[165] provides grant-in-aid for projects focused on the development of cold chain facilities for farm infrastructure, distribution hubs, irradiation facilities, and refrigerated vehicles. This includes cold storage, deep freezers, milk chillers, milk processing units, refrigerated/insulated transport, and retail solar-powered refrigerated carts. In addition, the scheme allows applications of renewable energy technologies (including solar) of up to USD 46,667 per project (as per MIDH norms).

The benefits provided to the eligible entities are grant-in-aid for:
(I) storage infrastructure at 35% in general areas and 50% in other defined areas (i.e. North East, Himalayan States, Islands, and Integrated Tribal Development Program Areas), and
(ii) value addition/processing infrastructure and irradiation facilities at 50% in general areas, and 75% in other defined areas

A maximum grant of USD 1.3 million is available per project. The eligible entities that can seek assistance under this scheme are partnership/proprietorship firms, companies, cooperatives, SHGs, FPOs, NGOs, central/state Public Sector Undertaking (PSU), etc. The project grant is co-financed with equity of at least 20% (for general areas) and 10% (for other defined areas). The estimated budget for 2020-21 is USD 46.53 million.[166]

[163] Financing facility under 'Agriculture Infrastructure Fund': Scheme Guidelines; Ministry of Agriculture and Farmers' Welfare; GoI; 2020 (Link)
[164] Press Release on Agriculture Infrastructure Fund by the Prime Ministers' Office (Link)
[165] Scheme for Integrated Cold Chain and Value Addition Infrastructure: Operational Guidelines; Ministry of Food Processing Industry; December 2019 (Link)
[166] Detailed Demand for Grants 2020-21; Ministry of Food Processing Industry (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.1 Existing Policy Framework in India

There are two cold chain infrastructure development schemes in the dairy sector that provide financial assistance in the form of concessional loans and back-ended capital subsidies. Firstly, the Animal Husbandry Infrastructure Development Fund (AHIDF) of USD 2 billion provides concessional loans to establish dairy processing, value addition infrastructure, meat processing, and animal feed plants.[167]

> AHIDF: The loan can be used for 90% of the project cost with an interest subvention of 3% p.a. The moratorium period for the principal loan amount is two years with a six-year repayment period thereafter. The eligible entities under AHIDF are FPOs, micro, small and medium enterprises (MSMEs), entrepreneurs, Section 8 companies[158], and private companies.

The beneficiary contribution can be a maximum of 10% for micro and small units, 15% for medium units and 25% for other entities.[159] The budget for AHIDF is for three years from 2020-21 onwards. Secondly, launched in 2010, NABARD's Dairy Entrepreneurship Development Scheme[170] extends financial assistance to set up small dairy farms and various project components including cold storage and chilling units.

> DEDS: The government provides a back-ended capital subsidy at 25% ofthe project cost (subject to ceilings) for:
> (I) bulk milk cooling units with capacity of up to 5000-litre, and a project cost of up to USD 26,667, and
> (ii) cold storage facilities with project costs of up to USD 44,000

The eligible beneficiaries are farmers, individual entrepreneurs, SHGs, NGOs, dairy cooperative societies, milk unions, milk federations, companies, groups of organised and unorganised sectors. Entrepreneurs must contribute 10% of the project cost as margin money for loans beyond USD 1,333. For 2019-2020, the total budget outlay[171] of the scheme was USD 43.33 million. Between June-July 2020, NABARD released subsidies worth USD 10 million to 12,417 beneficiaries.[172] Across both these dairy sector schemes, there is no clarity regarding assistance for usage of renewable technologies like off-grid solar refrigerators.

Financial assistance for the development of cold chain infrastructure across market segments through these schemes relays a positive market signal to companies in the off-grid solar refrigeration sector. Potential customers of off-grid refrigeration may be interested in exploring new technologies that assure reliable electricity supply with concessions available from these targeted schemes. Thus, government assistance could be a push factor that enable eligible entities to make investment decisions for viable off-grid solar refrigeration systems.

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[167] Press Release on Approval of Animal Husbandry Infrastructure Development Fund; June 2020 (Link)
[168] Note: Section 8 companies are companies formed for a charitable or non-profit purpose and registered under the Ministry of Corporate Affairs (Link)
[169] Implementation Guidelines for Animal Husbandry Infrastructure Development Fund; Ministry of Fisheries, Animal Husbandry and Dairying; 2020 (Link)
[170] Brochure for Dairy Entrepreneurship Development Scheme (Link)
[171] Website - Dairy Entrepreneurship Development Scheme 2019-20; National Bank for Agriculture and Rural Development (Link)
[172] List of Beneficiaries Benefited under Dairy Entrepreneurship Development Scheme June-July 2020; NABARD (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.1 Existing Policy Framework in India

Table 7: Summary table of relevant schemes for off-grid solar refrigeration

Relevant Ministry	Scheme	Main Provisions	Benefits	Budget Outlay
Ministry of New and Renewable Energy (MNRE)	Scale up of Access to Clean Energy for Rural Productive Use	**Objective:** Promote RE technologies (e.g. solar cold storage, solar dryers, solar aerators, etc.) for rural productive uses/livelihoods **Eligibility:** Buyers of RE technology	Subsidy of 30% on either the benchmark or tender cost	USD 23.04 million (Total project cost for 2018-19 and 2019-20)
Ministry of Agriculture and Farmers Welfare (MoAFW)	Mission on Integrated Development of Horticulture (MIDH)	**Objective:** Promote technology for post-harvest management, including cold storage units **Eligibility:** Individuals, group of farmers/consumers, partnership/ proprietary firms, SHGs, FPOs, companies, corporations, cooperatives, local bodies, etc.	• Credit-linked back ended subsidy at 35% in general areas (GAs) and 50% in North East (NE) states and Hilly States • 100% of invoice cost of up to USD 46,667 per project for addition of alternative techn-ology (including solar & PCM)	USD 244 million (2020-21) for the NHM and HMNEH sub-schemes[173]
	Agriculture Infrastructure Fund (AIF)	**Objective:** Establish a debt financing facility to offer credit via banks for post-harvest management infrastructure **Eligibility:** Farmers, FPOs, SHGs, agri-entrepreneurs, start-ups, cooperative societies, PPP projects, etc.	Concessional loans with interest subvention of 3% p.a. up to a limit of USD 0.27 million, applicable for a maximum period of 7 years.	USD 1.3 billion (2020-21)
Ministry of Food Processing Industries (MoFPI)	Integrated Cold Chain and Value Addition Infrastructure	**Objective:** Implement cold chain facilities as components of farm level infrastructure, distribution hubs and irradiation facilities. Allows application of RE technologies up to USD 46,667 per project (MIDH norms) **Eligibility:** Partnership/ proprietorship firms, companies, cooperatives, SHGs, FPOs, NGOs, PSUs, etc.	• Grant-in-aid for: (I) Storage infrastructure at 35% in Gas and 50% in NE, Himalayan states, Islands, & Integrated Tribal Development Program (ITDP) Areas; and (ii) Value addition / processing infrastructure / irradiation facilities at 50% in GAs and 75% in other areas, as above • Maximum value of USD 1.3 million per project	USD 46.53 million (2020-21)
Ministry of Fisheries, Animal Husbandry and Dairying (MoFAHD)	Animal Husbandry Infrastructure Development Fund (AHIDF)	**Objective:** Enable financing to establish dairy processing, value addition infrastructure, and animal feed plant, etc. **Eligibility:** FPOs, MSMEs, entrepreneurs, Section 8 companies, and private companies with 10% equity	90% of the project cost provided as a concessional loan with interest subvention of 3% p.a., with 2 years moratorium period for the principal loan amount and 6 years repayment period thereafter.	USD 2 billion (2020-21 to 2022-23)
	Dairy Entrepreneurship Development Scheme	**Objective:** Extend financing to set up small dairy farms and infrastructure like cold storage and chilling units **Eligibility:** Entrepreneurs, farmers, SHGs, NGOs, cooperatives, companies. Entrepreneurs contribute 10% of project cost for loans beyond USD 1,333	Back-ended capital subsidy of 25% of project cost (33.33% for SC/ST) subject to ceilings for: (i) Bulk milk cooling units with capacities up to 5000 litre and project cost up to USD 26,667; and (ii) Cold storage facilities with project costs up to USD 44,000	USD 43.33 million (2019-20)

[173] Administrative Approval for the MIDH Scheme in 2020-21, Ministry of Agriculture and Farmers Welfare (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.2 Development Support Programs on Innovations in India

In recent years, the off-grid solar refrigeration sector has gained momentum with focused interventions by development partners in India. Through their programmatic interventions, development partners are providing technical assistance to the government for policy design and implementation in the off-grid solar sector, supporting companies in raising funds through challenge/innovation funds, and assisting companies in business and financial planning via incubation programs. Some of the most prevalent programs[174] targeting development in the off-grid solar refrigerator sector have been briefly described below:

Since 2012, the 'Lighting Asia' program by the International Finance Corporation (IFC) has been one of the key programs in the off-grid solar sector in India. In its current phase, the program aims to improve access to clean and affordable energy by promoting off-grid lighting and DC appliances in the rural areas of Bihar, Uttar Pradesh, Rajasthan, Odisha and Assam.[175] The overarching objective of the program is to accelerate the development of markets for quality off-grid solar solutions and achieve effective penetration of these solutions among last mile market segments in rural areas. Program activities include supporting quality assurance of off-grid solar products, undertaking market studies and analysis, fostering business-to-business market linkages, conducting capacity building, facilitating business development for companies, and increasing consumer awareness. The program supports a value chain development approach covering commercial supply and demand prospects of off-grid systems. This includes manufacturing, distribution, finance, and supply chain management. In addition, IFC supports CLASP tested off-grid solar products.

Another aspect of ecosystem building is offering financial assistance and business planning support to clean energy companies to develop and scale-up innovative renewable energy solutions. This is enabled by the United Nations Industrial Development Organization (UNIDO) through its accelerator program, 'Facility for Low Carbon Technology Deployment (FLCTD)'[176], in partnership with the Bureau of Energy Efficiency (BEE). Initiated in 2015, the five-year program is funded by the Global Environment Facility (GEF) with a grant of USD 8.7 million and co-financing of USD 59.7 million.[177] This program provides support to selected clean energy companies on aspects related to business mentoring, technology deployment, replication and scale-up. The selection of companies implementing low carbon technologies to improve energy efficiency is undertaken through an 'Innovation Challenge' competition every year. The companies can be awarded a grant up to USD 50,000. The six thematic areas of energy efficiency are as follows: waste heat recovery, space conditioning, pumps/pumping systems, industrial IoT, industrial resource efficiency and electrical energy storage for 2020. In 2019, under the space conditioning criteria, the selected companies were Promethean Power Systems for a milk-can cooling system, Inficold for solar-powered instant milk chillers, and Tan90 Thermal Solutions for portable solar cold storage. For the refrigeration sector, it is expected that technologies supported through the FLCTD will achieve savings worth of 6,000 GWh of electricity and 4.8 m CO2eq over the duration of the program.[178]

[174] Note: This brief description only lists the key activities pertaining to technology and innovation that supports off-grid solar refrigeration across each of these programs. This does not describe all the initiatives being supported by these agencies under the purview of these projects with respect to off-grid solar sector.
[175] Website - Lighting Asia Program; IFC (Link)
[176] Website – Facility for Low Carbon Technology Deployment Program; UNIDO (Link)
[177] Website - Facility for Low Carbon Technology Deployment Program; GEF (Link)
[178] Facility for Low Carbon Technology Deployment: Project Identification Form; GEF; 2015 (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.2 Development Support Programs on Innovations in India

Transforming Inclusive Energy Markets (TIME)' is a five-year accelerator program (2016-2021) funded by the Foreign, Commonwealth and Development Office (FCDO) and Shell Foundation with a total committed value of USD 78 million.[179] It supports early-stage development and scale up of innovative business models and technologies aimed at accelerating access to energy for households, farmers and companies in rural areas of Africa. As a part of this program, it provides support to companies in other geographical areas (including India) to scale operations in Africa. For example, Inficold (a company providing solar cooling solutions) has been granted around USD 1 million[180] to test and install affordable off-grid solar refrigeration solutions for farmers and agri-businesses in India and other African countries.[181]

FCDO is also funding a research and innovation program called 'Low-Energy Inclusive Appliances (LEIA)' to promote efficient end-use appliances for off-grid and weak-grid areas in developing regions of Africa and South Asia. This includes technologies such as off-grid refrigerators, fans, solar water pumps and televisions. The total funding value of this five-year program is USD 24 million.[182] LIEA's objective is to accelerate access to energy services by doubling energy efficiency and halving the cost of selected high-priority off-grid appliances and innovative technologies. The five key components of the program are as follows: market stimulation and incentives to catalyse innovation, development of quality assurance services and product testing, marketplace education, coordination and communication, market intelligence and technology promotion, and research and development to leverage co-investments and build partnerships. The program is being implemented by CLASP and the Energy Saving Trust.[183]

The United Nations Development Program (UNDP) and GAVI alliance are supporting the government to strengthen the vaccine supply chain management system including cold chain infrastructure. The overall aim of the Electronic Vaccine Intelligence Network (eVIN) Program is to improve the efficiency of vaccination systems by operationalising a web-based vaccine management system across 521 districts in India. This is a five-year program (2017-2022) with a total project budget of USD 29 million. Some of the key components of the program are building the capacity of government officials on cold chain logistic management, digitalising vaccine stocks to address shortages, enabling real-time monitoring of temperatures of vaccine cold storage, and improving vaccine storage infrastructure, including the deployment of solar refrigerators.[184] By 2017, 20 solar refrigerators and 45 sets of solar equipment were installed at various cold chain points across the states of Jharkhand, Rajasthan, Uttar Pradesh, Assam, Chhattisgarh, Madhya Pradesh, Manipur, Nagaland, and Odisha.[185]

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[179] Report of the Trustees and Financial Statements 2019; Shell Foundation (Link)
[180] Web Article - The Cool Factor: Shell Foundation-Backed Start-up Inficold is Preserving India's Fruits, Vegetables, Milk; September 2019 (Link)
[181] Web Article -Three Insights into the Cold Chain Market in Rural India; May 2017 (Link)
[182] Low Energy Inclusive Appliances; FCDO (Link)
[183] About Low Energy Inclusive Appliances (LEIA) Program; Efficiency for Access (Link)
[184] Web Article - Improving Vaccination Systems (EVIN); UNDP (Link)
[185] Immunization Cold Chain and Vaccine Logistics Network Factbook; Ministry of Health and Family Welfare, GoI; 2017 (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.2 Development Support Programs on Innovations in India

The 'Efficiency for Access Research and Development Fund' provides grant funding to companies for accelerating research and development on off-grid cooling technologies. This fund is supported by UK aid and IKEA foundation. In 2019, as a part of a cooling technologies call, 13 companies received funding amounting to a total value of USD 2.23 million.[186] Two companies Devidayal Solar Solutions Pvt. Ltd. and Promethean Power Systems raised ~USD 122,000 each. This was grant funding for projects in the agriculture and dairy sector respectively in India. Devidayal Solar plans to pilot a transportable cold chain system with solar powered DC refrigerators to reduce food wastage. Promethean Power proposes to use thermal energy storage systems to power batteries for milk chilling. This will replace unreliable diesel generators and improve chilling efficiency for dairy farmers.[187]

These programs have the potential to propel market growth in the off-grid solar refrigeration sector. Government and financial institutions generally attach a higher risk of investment towards new and innovative solutions. This hinders growth for emerging renewable energy businesses with limited proof-of-concept. Herein, development support programs play a key role in establishing the initial ecosystem for innovation and building evidence on the need and impact of new technologies (like off-grid solar refrigerators). This programmatic support from multilateral and bilateral agencies can influence policymaking and encourage investment from other ecosystem players for innovative technologies like off-grid solar refrigeration.

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[186] Website – Research and Development Fund; Efficiency for Access Coalition (Link)
[187] Research and Development Fund Project Spotlights: Cooling Call; Efficiency for Access Coalition; April 2020 (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.2 Development Support Programs on Innovations in India

Table 8: Summary table of key development support programs in the off-grid solar refrigeration sector in India

Funder	Program and Duration	Main Provisions	Value
International Finance Corporation (IFC)	Lighting Asia 2012-ongoing	**Objective:** Accelerate market development for quality off-grid solar solutions and improve penetration of these solutions among last mile market segments in rural areas of Bihar, Uttar Pradesh, Rajasthan, Odisha and Assam. **Key Components:** Engage with private sector to remove market barriers, foster market linkages, provide market intelligence and raise consumer awareness	n/a
Global Environment Facility (GEF)	Facility for Low Carbon Technology Deployment (FLCTD) 2015-2020	**Objective:** Facilitate adoption of low-carbon technologies across India; by deploying and scaling up innovative energy efficient technologies aimed at reducing GHG emissions. **Key Components:** Conduct annual innovation challenges across different thematic areas (including space conditioning), provide business and technology mentoring support to entrepreneurs, support deployment of award winning innovations, enable technology verification, and offer networking opportunities with investors and industry stakeholders.	USD 68.5 million
Foreign, Commonwealth and Development Office (FCDO)/Shell Foundation	Transforming Inclusive Energy Markets (TIME) 2016-2021	**Objective:** Accelerate access to modern energy services for low-income households and small businesses (mostly in the African region) **Key Components:** Support applied research and innovation of clean energy solutions, create an enabling policy and market ecosystem, enable financial innovation, develop innovative business models, and foster partnerships.	USD 78 million
Foreign, Commonwealth and Development Office (FCDO)	Low-Energy Inclusive Appliances (LEIA) 2017-2022	**Objective:** Undertake research and innovation to promote efficient end use appliances for off-grid and weak-grid areas in developing regions of Africa and South Asia. **Key Components:** Market stimulation and incentives, quality assurance and product testing, knowledge management, market intelligence and technology road mapping, research and development co-investments.	USD 24 million
United Nation Development Program (UNDP)/ GAVI alliance	Electronic Vaccine Intelligence Network (eVIN) 2017-2022	**Objective:** Improve the efficiency of vaccination systems by operationalising a web-based vaccine management system across 521 districts in India. **Key Components:** Design and implement a digital vaccine supply chain network, facilitate real time monitoring of vaccine storage temperatures, undertake capacity building of government personnel for vaccine and cold chain logistic management, and improve vaccine storage infrastructure (including solar refrigerators).	USD 29 million
UK Aid/IKEA Foundation	Efficiency for Access Research and Development Fund 2019	**Objective:** Provide funding for research and development of innovative cooling technologies (focus on refrigeration, cold chain and fans) for off-grid and weak-grid areas, mostly in Asia and Africa. **Key Components:** Provide financing for research and development of innovative technologies and support demonstration of projects.	USD 2.23 million (grant to 13 companies)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.3 Financing Options for Off-Grid Solar Refrigeration Systems

To propel the growth of the off-grid solar sector with a focused interest on the refrigeration segment, impact investors and venture capital funds are channelling finance through debt and equity capital. Some of the key investors in this segment are Acumen, Sangam Ventures, Sathguru Catalyser, Omnivore, and Caspian, among others. In 2017, Acumen Fund, a social venture capital investor, launched the USD 20 million 'Pioneer Energy Investment Initiative' (PEII).[188] This initiative invests in clean energy companies focused on developing innovative solutions in the areas of energy generation and usage. As of February 2020, Acumen had made two investments in the productive use appliances sector.[189] Similarly, by 2019, Caspian, a social impact investment firm, had invested USD 17 million in the affordable and clean energy sector.[190] In addition, companies enabling energy access through solar powered refrigeration systems like Promethean and Inficold have also raised financing from Sangam Ventures - an early-stage venture fund. In the sector of agriculture and food systems, Sathguru Catalysers and Omnivore are impact investors providing funding for innovative RE technologies. Omnivore has made nine investments during the 2020 financial year. Sathguru Catalysers, through its 'Innovation in Food and Agriculture Fund (IFAF)', provides investments to companies that propel technological development including in off-grid solar refrigerators for the storage of fruits and vegetables.[191] Details of some recent investments in off-grid solar refrigeration are given in Table 9.

Table 9: Recent investment deals for solar refrigerators

Investor/ Financial Institution	Company	Type	Year	Value (USD million
Sangam Ventures[192]	Inficold	Equity	2018	0.25
1Crowd, Infuse Ventures, and Ankur Capital[193]	TESSOL	Equity	2018	Not disclosed
Caspian, Hivos-Triodos Fund, Sathguru Catalyser's Innovation in Food & Agriculture Fund[194]	Ecozen	Equity	2019	6.00
Acumen[195]	Promethean Power Systems	Not disclosed	2019	1.00

[188] Website – About Acumen Fund: Pioneer Energy Investment Initiative; GOGLA (Link)
[189] Web Article - Where is All the Investment in Solar-Powered Productive Use Appliances?; Next Billion; Feb 2020 (Link)
[190] Caspian Impact Investments Social Performance Report 2018-19; Caspian (Link)
[191] Website - Innovation in Food and Agriculture fund; Sathguru Catalyser Advisors Private Limited (Link)
[192] Web Article -From Cooling Tech for Intel to Chilling Milk Even Without Electricity, The Journey Of Inficold Founders; Economics Times; Oct 2018 (Link)
[193] Web Article - Tessol raises follow-on equity funding; July 2018 (Link)
[194] Web Article - India's Ecozen closes Series A on $6m to help farmers reduce spoilage; AgfunderNews; December 2019 (Link)
[195] Web Article -Acumen Invests in Promethean Power Systems; October 2019 (Link)

4 Ecosystem of Off-Grid Solar Refrigeration Systems in India

4.3 Financing Options for Off-Grid Solar Refrigeration Systems

In addition, there are multiple funds targeted at the growth of decentralised renewable energy applications in India. One of the recent funds raised to support the clean energy sector is a USD 5 million fund by cKers finance. This fund aims to catalyse the growth of distributed solar energy, including solar refrigerators.[196] In 2019, Nabventures Fund I was announced by NABARD. It had a corpus of USD 66.67 million and green-shoe option of USD 26.67 million for equity investments in food, agriculture, and rural start-ups.[197] NABARD has invested USD 118.13 million across 41 portfolio companies developing infrastructure and capital in areas such as solar micro cold storage, renewable energy, solar dryers, and waste management.[198] In addition, grant funds are also supporting companies pioneering clean energy solutions. For example, the USD 7.9 million PACEsetter fund, a partnership between the Indian and American government, is focused on off-grid renewable energy applications with a capacity of less than 1 MW.[199]

These ecosystem financiers are providing commercial investment to early-stage companies, thereby supporting innovation in the off-grid solar refrigeration sector. It is expected that the introduction of alternative financing mechanisms, such as results-based financing, risk guarantee funds, and design-stage grants, will further de-risk potential investments and herald growth in the off-grid solar sector.

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[196] Web Article - Distributed solar lender cKers Finance raises $5 million from US investor New Energy Nexus; Pv Magizine; March 2020 (Link)
[197] Web Article - Nabventures Launches Maiden Fund to Back Agri, Food and Rural Start-Ups; Economic Times; May 2019 (Link)
[198] Sustainability Report 2018-19; NABARD (Link)
[199] Website – PACEsetter Fund; MNRE (Link)

5 The Impact of Off-Grid Solar Refrigeration Systems in India

The use of off-grid solar refrigerator can support India in achieving its SDG targets, as well as create value for society, through for example, generating higher incomes. Off-grid solar refrigeration impacts 7 out of 13 SDGs directly and others indirectly. The direct SDGs include SDG 1 (poverty reduction), SDG 2 (food security), SDG 3 (good health and wellbeing), SDG 5 (gender equality), SDG 7 (clean energy), SDG 8 (jobs and entrepreneurship), and SDG 13 (climate action). The specific impacts of off-grid solar refrigeration on consumers, businesses, environment, and economy are highlighted below:

Impact on Consumers

By supporting reductions in food waste and losses through proper refrigeration, off-grid solar refrigerators can contribute to improved food security (SDG 2). Along with food security, it also allows households to save capital by reducing the number of market trips (e.g. travel only once or twice a week), decreasing expenditure on cooking fuel, and reducing food waste. Along with cost saving, off-grid solar refrigerator users have observed additional benefits from an increased variety in diets, lower stress resulting from the ability to store raw food, and increased convenience from the ability to store cooked food, which also contributes to SDG 3 (good health and well-being). Refrigerator ownership is also associated with increased social capital, wealth, and economic stability for the community. It allows consumers to help and host neighbours, which results in deeper community bonds.[200] Household off-grid solar refrigerators and other off-grid appliances like electric cook stoves can also be important contributors to greater gender equality (SDG 5), as they reduce time poverty for women.

The implementation of off-grid solar refrigerators at the farm-gate can improve livelihoods (SDG 1) for small holder farmers by reducing the post-harvest losses of highly perishable crops, and by increasing profits through enabling greater bargaining power in the marketplace. A group of smallholder farmers can collate funds and buy a refrigerator to store perishable fruits and vegetables. This prevents distress selling of the produce in the market (especially in the season of high production). According to a case study by Ecozen, off-grid solar refrigerators has the ability to enable more than a 40% increase in the profits for the smallholder farmers; they breakeven after two years.[201] The refrigerators also enable micro-enterprises to improve livelihoods by selling high-margin cold drinks, milk and processed foods, which is otherwise difficult to sell in off-grid and weak-grid areas.

Off-grid solar vaccine storage enables vaccine distribution and storage in remote areas, which contributes to SDG 3 (good health and well-being). For example, in India, the installation of a solar vaccine storage facility at a PHC enabled immunisation for 800 people in a month in rural areas.[202]

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[200] How Innovation in Off-Grid Refrigeration Impacts Lives in Kenya; CDC Investment Work; October 2019 (Link)
[201] Case Study on Ecozen; World Bank (Link)
[202] SELCO Foundation Annual Report 2016-17 (Link)

5 The Impact of Off-Grid Solar Refrigeration Systems in India

Impact on Businesses

The availability of cooling capacity at rural micro-enterprises has impacted socio-economic growth positively. It has increased purchasing power, contributing to SDG 1 (poverty reduction) and SDG 8 (entrepreneurship) in a few countries. For example, a Global LEAP survey data from Uganda indicates that micro and small enterprises (MSEs) that had purchased off-grid refrigerators increased their daily incomes 2.5-fold on average (from USD 29 to USD 70); half of these companies used the off-grid refrigerator to expand into new business lines (i.e. food and drink sales).[203] In India, a restaurant in Karnataka increased its profit by USD 53 per month after the installation of a solar powered refrigerator. This reduced the wastage of perishable produce and expanded the product range.[204]

By targeting SDG 5 (gender equality) and SDG 8 (entrepreneurship), the off-grid solar refrigeration segment creates commercial opportunities. It particularly enables women by encouraging them to start new businesses. These businesses can be focused on selling perishable goods (e.g., milk, vegetables, fruits and fish), cold water, and cold drinks from home. Women can store multiply commodities in the refrigerator based on the local demand for perishable produce and chilled products in rural areas.

Environmental Impact

Refrigeration-on-wheels, based on the business-as-usual diesel solution, results in environmental degradation and impacts air quality, which has a substantial impact on the health of individuals. As urbanisation increases, off-grid solar refrigeration for reefer vehicles and refrigerator-on-wheels can reduce air pollution levels and thus contribute to SDG 7 (clean energy) and SDG 13 (climate action). The majority of off-grid solar refrigerators operate on eco-friendly refrigerants replacing harmful chlorofluorocarbons, thus preventing a further depletion of the ozone layer.

Off-grid appliances, especially refrigerators, are increasingly becoming a critical element of the broader global push towards greater energy efficiency and GHG reductions. According to the Food Agriculture Organisation (FAO), 'every wasted tonne of fruits and vegetables results into approximately 1.1 CO2eq. emissions in the South Asia region'.[205] It is also estimated that food loss and waste is the third largest contributor to the emission of greenhouses gases in the world.[206] The use of off-grid solar refrigerators at the farm-gate level can reduce the emission of these GHG gases by preserving perishable items, thus contributing to SDG 13 (climate action). There is an opportunity for meeting the rising energy demand by implementing energy efficient off-grid appliances. This would minimise costs to consumers through energy savings. It would also have a net impact on the environment, thereby contributing to SDG 13.

[203] Off-Grid Appliance Performance Testing: Results and Trends for Early-Stage Market Development; Lai, E., Muir, S. & Erboy Ruff, Y; May 2019 (Link)
[204] Innovative Solar Projects; SELCO Foundation (Link)
[205] The State of Food and Agriculture 2019. Moving Forward on Food Loss and Waste Reduction; FAO; 2019 (Link)
[206] Web Article - What's Food Loss and Waste Got to Do with Climate Change?; World Resources Institute; Dec 2015 (Link)

5 The Impact of Off-Grid Solar Refrigeration Systems in India

Economic Impact

Off-grid appliances support progress toward SDG 1 (poverty reduction) by providing livelihood opportunities to the economically disadvantaged population who can use them to earn or augment incomes. The widespread use of refrigerators by off-grid and weak-grid households (as well as others) has the potential to generate billions of dollars in annual savings.[207] With an expanded cold chain, farmers can preserve perishable fruits and vegetables by transporting them in refrigerated trucks, and families can buy a greater variety of foods at grocery stores. Off-grid productive use appliances create the foundational demand for energy services and help create jobs for the rural population. The most far-reaching impact of these appliances is the incremental role they can play in driving demand for energy and supporting the achievement of universal energy access by 2030 (SDG 7).

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[207] How Access to Energy can Influence Food Losses: A Brief Overview; FAO; 2016 (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

Enabling an ecosystem for the promotion of off-grid solar refrigeration needs multiple interventions. These need to be directed to solve the challenge of low market penetration, which arises mainly due to poor awareness among consumers and financiers, limited regulatory push, the high upfront capital cost of off-grid solar refrigeration technology, a lack of information on consumer market segments, and limited consumer and company financing options.

Key recommendations pertain to three overarching themes:
a) enhancing the policy regime for off-grid solar refrigeration,
b) providing nuanced financial support to companies (to support research and development of new technologies) and consumers (to support the high capital expenditure), and
c) creating an enabling ecosystem for market development

These have been defined for major actors or ecosystem players such as the government, donor agencies, financial institutions, companies, and other ecosystem players (like private associations, think-tanks, non-governmental organisations).

6.1 Recommendations for the Government to Support Off-Grid Solar Refrigeration

Design targeted policies for off-grid solar refrigeration to achieve access to energy targets aligned with SDG 7.
At the national level, relevant sectoral ministries (such as MoFPI, MoFAHD, and MoAFW) can include off-grid solar refrigerators as one of the key technologies across multiple policies that aim to deliver cold-chain infrastructure in the agriculture, dairy and healthcare sectors. These policies need to also be aligned to SDG 2, SDG 3 and SDG 4. These policies will enable state department to implement dedicated projects with subsidies in the off-grid solar refrigeration sector. For example, the Mission for Integrated Development of Horticulture (MIDH) suggests the provision of subsidies for adopting alternative technologies (e.g. PCM, solar PV panels, solar thermal systems, or vapour absorption) for cold storage in the agriculture and dairy sector. However, there is no publicly available information on the uptake of these norms by state departments implementing sub-schemes under the MIDH. Furthermore, existing government policies on solar energy are skewed towards promoting decentralised renewable energy through solar rooftops, mini-grid systems, home lighting systems, and others. Apart from solar water pumps, there is limited policy focus on productive use appliances. This exemplifies the need for MNRE to design a comprehensive policy providing subsidies, credit guarantee schemes or tax incentives for the adoption of off-grid solar refrigerators enabling cold-chain infrastructure across all relevant market segments. These policy interventions will help resolve the upfront cost barriers faced by consumers, ease financing for companies, and raise consumer awareness. The Draft India Cooling Action Plan (ICAP) of 2018 also suggests linking incentives offered for cold chain development to the introduction of more energy efficient solutions.[208]

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[208] Draft Cooling Action Plan; Ministry of Environment, Forest and Climate Change; GoI; September 2018 (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.1 Recommendations for the Government to Support Off-Grid Solar Refrigeration

Promote awareness on existing product testing methods and performance metrics for off-grid solar refrigerator technologies to improve consumers' and financial institutions' confidence on product reliability.

One of the key barriers for the uptake of off-grid solar refrigerators is a lack of brand recognition; consumers prefer and trust appliances by common and known brands (e.g. LG, Samsung, etc.). The government can promote existing product testing methods that enforce basic technical specifications/standards for off-grid solar products, such as the Lighting Global Quality Assurance Framework[209] or VeraSol/Global LEAP Test Method.[210] Standards like the VeraSol[211] test method offer a comprehensive standard for testing solar appliances (such as television sets, refrigerators, fans and solar water pumps). The three main parameters for testing of off-grid solar refrigerators are quality and durability, safety and consumer protection, and energy performance. These parameters include aspects related to packaging, product marking, user manual assessment user safety review, design and durability of refrigerator housing, cooling system and door serviceability and maintenance, and environmental impact considerations.[212] The MNRE can encourage and support companies in adopting the VeraSol Test Method for off-grid solar refrigerators. As per existing mandates, the Bureau of Indian Standards (BIS) enforces the standardisation of solar PV products, including solar panels, power converters, solar inverters, films, and storage batteries. The government can emphasize on energy performance reporting by the companies and truth-in-advertising for off-grid solar refrigerators. This will generate investor and consumer confidence where the efficiency and durability of the products is concerned, while mitigating perceived risks. This could lead to increased demand for the products and improved access to company and consumer financing.

Rationalise existing tariffs on solar components and provide tax incentives to companies manufacturing off-grid solar refrigerators to reduce capital costs.

The Government of India needs to rationalise import tariffs on solar panels, solar inverters, solar cells, and compressors to improve the competitiveness of the off-grid solar refrigeration industry in the near short-term. The MNRE has proposed the enforcement of a basic custom duty, which is around 20% on solar equipment, including solar panels, inverters and cells.[213] This is an increase from the existing safeguard duty, which is around 14.9%.[214] While this can boost domestic manufacturing of solar components in the next few years and reduce costs of components used for manufacturing off-grid solar refrigerators, it needs to be rationalised currently as it leads to higher capital costs of off-grid solar products. This impedes uptake of technology for off-grid rural customers who can least afford to pay. Thus, the government policies need to support the industry on issues like custom duties and other taxes. Furthermore, considering the government focus on domestic manufacturing, it can provide complementary tax benefits to companies. This will provide the required impetus to local manufacturing of off-grid solar refrigerators at reduced prices in the medium to long term.

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[209] Website - Lighting Asia Program: Quality Assurance Program (Link)
[210] Website – VeraSol Test Methods (Link)
[211] Ibid
[212] Global LEAP Off-Grid Refrigerator Test Method; April 2019 (Link)
[213] Web Article - Basic Customs Duty on Solar Equipment may hit SEZ Mfg. Facilities; Economic Times; June 2020 (Link)
[214] Web Article - Solar industry awaits finance ministry decision on safeguard duty or Basic Customs Duty; Financial Express; July 2020 (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.1 Recommendations for the Government to Support Off-Grid Solar Refrigeration

Create a national level fund targeted to support the local manufacturing of off-grid solar refrigerators with a specific provision of financial assistance to companies.
There is a need to provide financing for the customisation and scale-up of off-grid solar refrigerators across key market segments (like health, agriculture, dairy, households, and micro-enterprises). The Government of India can formulate a dedicated national level fund through contributions from the unutilised national/state level budgets designated for energy efficiency and cold-chain infrastructure development, as well as from the support of development partners and foundations. For instance, the National Horticulture Mission (NHM) and Horticulture Mission for North Eastern and Himalayan States (HMNEH) scheme had ~USD 8 million as an unutilized budget in 2017-18[215]; and the Dairy Entrepreneurship Development Scheme (DEDS) had ~USD 12 million in unspent funding in 2018-19[216].The proposed fund may be used for financing grant-in-aid projects to test and scale viable business models demonstrated by companies. This fund can be managed by the Bureau of Energy Efficiency (BEE), which is managing multiple programs for energy efficiency and productive-use appliances in India. In 2011, the government formulated the National Clean Energy and Environment Fund (NCEEF) financed by the clean environment cess charged on coal production/import. The NCEEF is used for financing government sponsored innovative projects in clean energy technologies to the extent of 40% of the total project cost. Financial assistance can be availed as a loan or viability gap funding. Till 2015-16, the government recommended 55 projects with a total viability gap funding of ~USD 4.6 billion[217].

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[215] State-wise Funds Allocation and Release under National Horticulture Mission and Horticulture Mission for North Eastern and Himalayan States in India (2015-16 to 2019-20), IndiaStat (Link)
[216] State-wise Number of Dairy Units Sanctioned, Funds Allocation and Amount Disbursed through the NABARD under the Dairy entrepreneurship Development Scheme in India (2014-15 to 2018-19), IndiaStat (Link)
[217] Note on National Clean Energy and Environment Fund (NCEEF), Department of Environment (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.2 Recommendations for Donor Agencies and Financial Institutions to Support Off-Grid Solar Refrigeration

Design innovative financial instruments like blended finance for supporting emerging and innovative business cases.
Donor agencies and private financial institutions (such as impact investors, venture capital firms, banks, non-banking financial companies (NBFCs), etc.) need to collaborate to extend financial support to companies through innovative financing mechanisms. Financing structures such as blended finance help mitigate investment risks by distributing financial risk across multiple instruments (such as equity, debt and grants, etc.). For example, an interest subvention support by a donor agency to off-grid solar refrigeration companies (on taking loans from NBFCs) can enable low-cost finance. Such financial instruments are critical for the development and expansion of new products, including off-grid solar refrigerators, which have limited proven cases to attract commercial finance.

Explore consumer financing options like revolving funds or viability gap funding to improve affordability of off-grid solar refrigerators.

Donor agencies or private foundations can partner with commercial financial institutions to enable low-cost loans for the purchase of off-grid solar refrigerators. To enable last mile consumer financing, some of the innovative financing mechanisms could be revolving funds or viability gap funding. For example, the SELCO Foundation has implemented a revolving fund in partnership with Tata Trusts to enable finance for farmers to purchase off-grid solar refrigerators. The initial capital for the fund is given by Tata Trusts. The cheaper capital from the revolving fund helps demonstrate the business model, and thus helps in unlocking capital from Micro Finance Institutions (MFIs) and/or NBFCs later. This fund is replenished with the repaid loan amounts, which in turn is used for financing new beneficiaries[218]. In addition, SELCO foundation also provides viability gap funding to local entrepreneurs for starting solar energy based businesses (e.g., off-grid solar refrigerators for hotel or local shops, solar sewing machine, and solar charged hawker lights) through its entrepreneur fund[219]. This fund is based on an interest subsidy scheme, which allows entrepreneurs to access loans at low interest rates of up to 5% from financial institutions[220].

[218] SELCO Foundation Annual Report 2018-19 (Link)
[219] Entrepreneur Fund; SELCO; 2017 (Link)
[220] Entrepreneur Fund: Case Studies From the Field; SELCO Foundation; 2017 (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.3 Recommendations for Companies to Strengthen Market Linkages

Provide advisory support to consumers across the value chain as an attractive package of services.
Companies need to create backward and forward market linkages for customers (such as farmers, dairy owners, and retail shop owners) as an incentive to adopt off-grid solar refrigerators. They will need to develop unique value propositions for each market segment. For example, they can help farmers access inputs at lower costs by leveraging their industry network and knowledge. They can also create buyer-seller linkages between micro-enterprises and producers (i.e. farmers and dairy owners) that have adopted their technology. These supply chain linkages can provide additional benefits to farmers and dairies, in terms of improved market share of their produce and increased income generation. This may reduce the perceived risk of off-grid solar refrigerators among customers and enhance their willingness to adopt. Overall, the provision of additional advisory support services by companies can provide a competitive advantage and improve their market share in the off-grid solar refrigeration sector.

Develop and demonstrate bankable projects and proof-of-concept to avail commercial financing.
Companies should approach financial institutions with a project report capturing bankable projects that include key information such as success factors, high profitability, repayment potential, and a reduced payback period. This will help financiers to understand the financial viability of the technology vis-à-vis other products in the same market segment. Companies can also highlight the positive environmental and social impact of the technology as additional intangible benefits to access credit lines. The demonstration of a bankable project provides risk assurance to the commercial bank on the feasibility of the business and thereby enables requisite investment.

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.3 Recommendations for Companies to Strengthen Market Linkages

Implement innovative business models that reduce upfront capital investment requirements (pay-as-you-use) to improve affordability of off-grid solar refrigerators.
Companies need to provide solar off-grid refrigerators to customers on a model that eases the requirement of upfront investment. For example, the build-operate-lease-transfer (BOLT) model can be experimented with where customers pay monthly instalments as a lease for a fixed duration of time. Once the company has received repayment on the capital and recurring costs, then the ownership of the technology can be transferred to the customer. Another model is pay-as-you-use, which allows customers to pay for cooling service based on the capacity of their usage. Companies can partner with energy-as-a-service companies like KPay to integrate their technology platform with off-grid solar refrigerators. KPay has three models for the provision of energy-as-a-service that includes pay-per-use, pay-per-time, and pay-per-ampere. In such systems, the off-grid solar refrigerator is embedded with a digital device that will switch cooling on or off based on the amount of payment made by the customers. These business models solve the challenge of high upfront cost of technology that has curtailed the market penetration of off-grid solar refrigerators. Across both these models, customers can make payments in instalments, hence improving affordability.

Generate consumer awareness on the benefits of the technology and availability of schemes to support market expansion.
Companies can develop dedicated consumer awareness programs (including village level awareness campaigns, television commercials, social media, and door-to-door pamphlet distribution) for each market segment on the benefits of off-grid solar refrigerators in terms of improved energy saving and enhanced productivity and lifestyle. This can also include information on various financial incentive schemes by the government for consumers to support access to this technology. The draft ICAP 2018 suggests fostering consumer awareness on the total cost of ownership vis-à-vis purchase cost. This will drive the market for efficient refrigerators. This endeavour may be supported by donor agencies, government, NGOs, and private foundations/associations. For instance, under the Lighting Asia Program, the IFC is implementing a consumer awareness program (called 'SuryodayTM – 'Zindagi Non-stop') in partnership with off-grid solar product manufacturers and distributors to promote the advantages of quality-certified solar lightning and solar home systems (SHS).[221] They have used an innovative approach of a campaign-on-wheels, whereby a van equipped with solar lanterns and SHS showcases films on the benefits of off-grid solar products.

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[221] Web Article - 'SuryodayTM – 'Zindagi Non-stop', Campaign to Promote Quality Solar Energy Products in Rural India; Lighting Asia Program (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.4 Recommendations for Other Ecosystem Players to Enhance Market Development of Off-Grid Solar Refrigerators

Establish a digital platform with data on technology applications and potential market segments to enhance knowledge about off-grid solar refrigerators.
Associations or think tanks can support the creation of a national repository with information on the application of technology across market segments to improve knowledge among varied stakeholder groups (including consumers, financial institutions, and government agencies, amongst others). This platform can compile existing data on key parameters, such as type of technology, key market players, business models, and preferred geographical location for each market segment. It can also provide technical information on energy consumption, ambient temperature, and hours of reliable energy supply for various technologies. The platform will help consumers to compare and select the most reliable and efficient off-grid solar refrigerators for their specific market segment. It will also strengthen market competition among companies and encourage manufacturing of reliable and required energy efficient technology. For example, the Ministry of Micro, Small and Medium Enterprises (MoMSME) and The Energy and Resources Institute (TERI) have collaborated to develop a digital platform called 'Sameeksha'; for the promotion of energy efficiency in small and medium enterprises (SMEs) in India[222]. This knowledge-sharing platform pools resources from various organisations/institutions on energy efficiency technologies (EETs) and provides a forum for industry to collaborate with ecosystem players. This platform provides information on energy consumption data of SMEs, demonstration videos of EETs, case studies on best practices of EET, cluster profiles of SMEs, and knowledge reports etc.; to achieve wider reach and scale of operations.

Design and implement a training program on financing of off-grid solar productive appliances for financial institutions in rural areas.
One of the main barriers for poor company financing is the limited understanding of the technology and product application by financial institutions, especially in rural areas. There is a need for capacity building of financial institutions (such as local branches of commercial banks, NBFCs, small finance banks, etc.) in rural areas on financing of innovative technologies/products like off-grid solar refrigeration. For example, the Bureau of Energy Efficiency (BEE), which is under the MNRE, has collaborated with the Indian Banks' Association (IBA) to implement a training of trainers (ToT) program on financing energy efficient products as a part of its energy efficiency financing platform initiative[223]. A similar program could be designed for financing off-grid solar refrigerators. BEE can collaborate with the Bankers Institute for Rural Development (BIRD) or IBA to design and deliver the training program. The aim of this program will be to enhance knowledge among local financial institutions on three critical aspects:
(I) need and impact of off-grid solar refrigerators across market segments, (ii) technical and financial feasibility of the technology, and (iii) proposed financial instruments relevant for this technology. This will help in last mile access to finance for consumers seeking loans to acquire an off-grid solar refrigerator and enable financing for companies for development and scale-up of technology.

[222] Website – Sameekhsa Platform (Link)
[223] Web Article - Energy Efficiency Financing Platform (EEFP); International Energy Agency (Link)

6 Key Recommendations to Improve the Market Ecosystem of Off-Grid Solar Refrigeration

6.4 Recommendations for Other Ecosystem Players to Enhance Market Development of Off-Grid Solar Refrigerators

Demand aggregation of off-grid solar refrigerators to achieve economies of scale and reduce unit price of the product for consumers. National level associations can undertake bulk purchase of off-grid solar refrigerators to drive market demand. This can reduce the high upfront capital cost of technology as well as promote domestic manufacturing. This demand aggregation may also enable financing for companies from formal sources, as it will enable them to bring the requisite collateral based on financial and physical asset strength. The 'Unnat Jyoti by Affordable LED for All' (UJALA) program implemented by the Energy Efficiency Services Limited (EESL) has been successful in distributing low-cost LED bulbs, LED tube lights and energy efficient fans across India. The demand aggregation strategy for LED bulbs led to a significant decrease in procurement price from USD 4 in 2014 to USD 0.5 in 2019[224].

Overall, the recommendations aim to enable companies to increase the market penetration of off-grid solar refrigerators through the requisite regulatory, technical, and financial support. This study has provided suggestions that can be prioritised for immediate implementation in the short to medium term (2-5 years) to build a sustainable ecosystem for the off-grid solar refrigeration sector in India.

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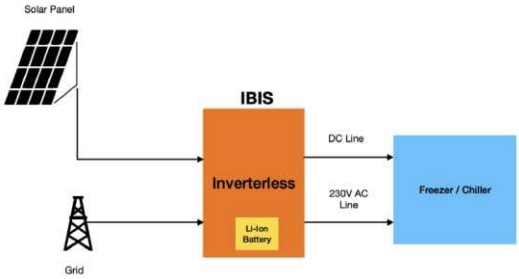
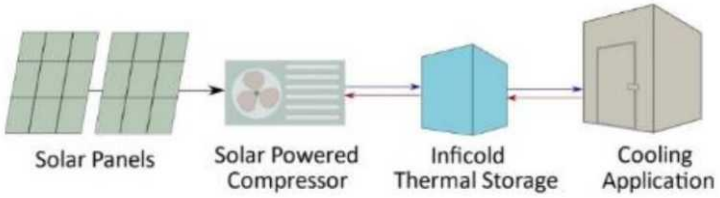
[224] Website - About the UJALA program, EESL India (Link)

7 Company Landscape

Company	Cygni Energy Private Limited (Cygni) specialises in solar power backup and DC micro-grid solutions. Their flagship product is inverter-less systems. Cygni also deploys productive appliances such as refrigerators, home lightning, power looms, and many more.
Technology	Cygni provides an energy efficient refrigerator solution through unique 48V DC solar inverter-less technology. This solution supports AC/DC interoperability and enables high energy efficiency output with the combination of energy access and energy efficient technology.  This system has an automatic calibrator controller to the operating voltage of 12V / 24V/48V DC. The system is connected to lithium ion batteries and a charge controller to avoid overcharging of the battery. It also has digital operational panel and auto temperature control mode. It is equipped with voltage control mode, which helps in avoiding deep discharge of battery. Cygni has many variants of inverter-less technology and one variant has an AC output through an inverter. In this variant, the inverter will be in bypass mode if the grid is available and would be turned 'on' only when there is a grid failure.
Applications	Household Micro-Enterprise Healthcare
Business Model	Cygni manufactures the refrigerators and the last mile distribution of the products is handled by authorised dealers/distributors.
Pictures	 

7 Company Landscape

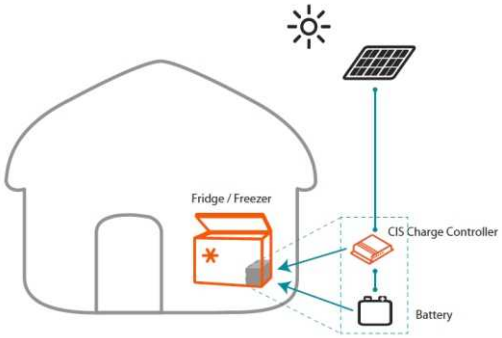
Inficold

Company	Inficold India Pvt Ltd is a technology start up that provides solar cold storage and solar milk coolers.
Technology	Inficold provides cooling through a direct expansion-based evaporating mechanism. It has developed an inverter-less solar integration for refrigeration systems, which reduces the overall system cost and improves solar utilisation. It has a PCM thermal battery based system which uses water as the phase change material. Water is an energy-efficient storage medium with the highest latent heat and zero capacity degradation when compared to other low-temperature PCM. The integration of solar with the thermal storage system does not require an inverter and battery to power the cooling unit, hence it has a lower maintenance cost. 
Applications	Dairy Farm-Gate
Business Model	Manufacturing of refrigerators, direct sales and last mile distribution of the products is handled by the Inficold in-house team.
Pictures	

7 Company Landscape

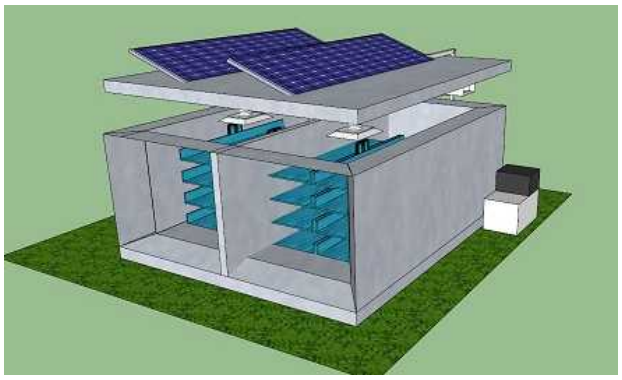
Company	Tan90 Thermal Solutions Private Limited has customers spread across 11 states in India. Tan90 works closely with Department of Horticulture, the Government of Tamil Nadu, Murugappa Group and other private farm-to-fork companies.
Technology	Tan90 enables affordable off-grid solar refrigeration that resemble an icebox, with each unit having a usable capacity of 50 litres. The unit is powered by PCM thermal batteries. Tan90 has developed a PCM for thermal energy storage that freezes at almost twice the pace of other gel pads available in the market. With the help of PCM, refrigeration is carried out by passive cooling. Tan90's PCM material for pharmaceuticals applications can retain the temperature for 96 to 100 hours in the temperature range of 2°C to 8°C.
Applications	Micro-Enterprise Farm-Gate
Business Model	Tan90 sells its product to FPOs. FPOs then channel the product to farmers on a rental basis.
Pictures	 

7 Company Landscape

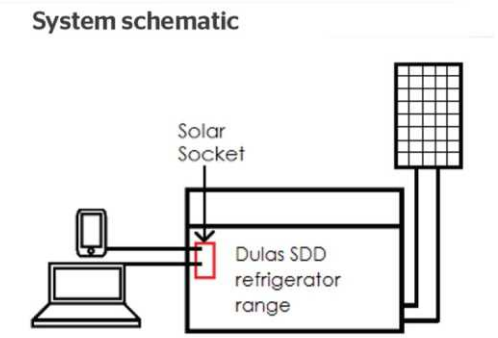
Company	Phocos is an off-grid solar solution company that maximises system reliability and minimises total cost of ownership. Phocos designs and delivers solutions for energy production, storage, and conservation, to enable universal access to reliable energy.
Technology	The Phocos DC chest refrigerator/freezer with BOOST feature offers a solution for off-grid and weak-grid refrigeration. The system is equipped with a brushless DC compressor. This compressor can be directly connected to batteries, and the mechanical thermostat of the system can help to operate the system as a refrigerator or freezer by simply adjusting it. Direct DC operation of the system eliminates wasted inverter energy. It can be powered with a 12 or 24 V battery. 
Applications	Households Micro-Enterprise
Business Model	Phocos manufactures the refrigerators, and the last mile distribution of the products is handled by authorised dealers/distributors.
Pictures	 

7 Company Landscape

PLUSS® | TECHNOLOGY FOR A BETTER WORLD

Company	PLUSS is a materials research and manufacturing company involved in the field of Specialty Polymeric Additives for enhancing polymer properties and PCMs for thermal energy storage.
Technology	PLUSS offers solar PV with PCM solutions for farm gate refrigerators. PCM filled heat exchanger plates are lined up on the inner side of the refrigerator wall. A condensing unit caters to the cooling requirement of 24 hours by charging the plates in 4-5 hours (during daytime). The PCM lining maintains the temperature of +2°C to +4°C for 16-20 hours per day. 
Applications	Healthcare Farm-Gate
Business Model	PLUSS provides specialty PCM to other solution providers. PLUSS also sells off-grid solar refrigerators directly to farmers or FPOs.
Pictures	

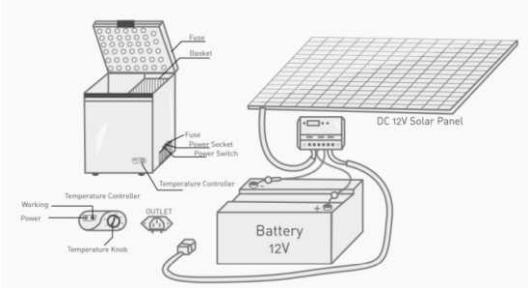
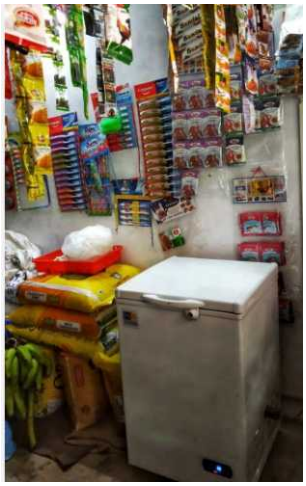
7 Company Landscape

Company	Dulas provides innovative solar-powered solutions to remote and off-grid locations. Dulas is a pioneer in solar-powered refrigeration systems and it supports the delivery of essential vaccines in developing communities across the world.
Technology	Dulas provides SDD refrigerators which are designed to be the most reliable vaccine storage solutions. Using an advanced non-corrosive PCM for the energy storage, its unique liquid freezes and thaws at +5°C. With an infinite cycle life and no requirement for super cooling[225], the company provides efficient PCMs for the cold chain. The internal PCM store cannot be damaged by over discharging or charging of the system and there is no need to replace the internal PCM. Dulas has designed the system to remove the risk of vaccine freezing, and it also meets the requirements of the latest WHO freeze protection standards. 
Applications	Healthcare
Business Model	Dulas is a manufacturer of off-grid solar refrigerators, and the last mile distribution of the products is handled by authorised dealers/distributors.
Pictures	 

[225] Note: Supercooling is the process of chilling a liquid below its freezing point, without it becoming solid.

7 Company Landscape

DEVIDAYAL SOLAR SOLUTIONS

Company	Devidayal Solar is an India-based company with a focus on providing off-grid solar solutions to the rural market. The company's vision and focus are designing and developing high quality, certified off-grid appliances like solar DC refrigerators, BLDC fans, and coolers.
Technology	The Devidayal solar refrigerator provides 24×7 reliable solar power with the use of an appropriate battery system (lead acid or lithium ion options) designed for overnight cooling. It also provides a manual adaptor to ensure AC/DC interoperability. In this case the grid power (AC) is used for charging batteries. 
Applications	Healthcare Household Micro-Enterprise
Business Model	Devidayal manufactures the refrigerators, and the last mile distribution of the products is handled by authorised dealers/distributors.
Pictures	 

7 Company Landscape

ecozen

Company	Ecozen Solutions is a technology company enabling farm-to-fork value chain for perishable products across India. Ecozen developed Ecofrost, a stand-alone solar powered cooling system designed to operate reliably in regions facing challenges of quality power supply. It has also developed and commercialised the ecoConnect platform. This platform enables agri-commodity businesses, retailers, food and beverages manufacturers, and residential societies to identify and procure quality produce directly from the farms.
Technology	Ecofrost is solar-grid hybrid cold storage. It can maintain product temperature between +4^{0}C and +10^{0}C. The cold storage has a humidity control range between 65% and 95%. A part of the energy generated from solar or grid is utilized for refrigeration operations, and part of it is used to freeze the thermal banks which are dependent on ice core technology. The ice core technology helps maintain the temperature of refrigerator during non-sunny hours. The compressor compacts the refrigerant and passes it to the condenser that cools the refrigerant by condensing it to a liquid state. The refrigerant is passed to the expansion valve, which regulates the amount of refrigerant used for meeting the load requirement. In this case, the load is fruits or vegetables that are stored in the cold room. The cold and pressurized refrigerant then passes to the evaporator, which then absorbs the heat from the commodities stored in the cold room. Along with the evaporator, there are four fans (vertically installed) that help circulate the air in all directions within the cold room to maintain temperature uniformity across the cold room.
Applications	Pre-cooling and staging of perishable fruits and vegetables at: Farm-Gate Packhouse Mandis
Business Model	Ecozen has adopted various business models like cash and carry, lease a cold room, and community model.
Pictures	 

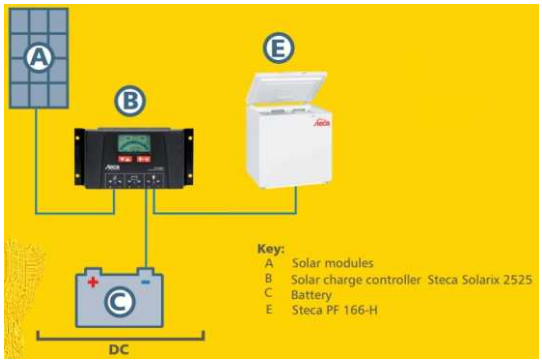
7 Company Landscape

GESS

Company	GESS International FZC LLC and ANCAR India Pvt. Ltd. design and develop energy efficient products which includes the air conditioner and refrigeration range from RAC, CAC, chillers, cold rooms, heat pumps etc. The product use natural refrigerants like ammonia, CO2, R290, R600A and other low GWP refrigerants.
Technology	GESS uses off-grid solar technology along with thermal storage and avoids battery for back up. Type of Technology being used by GESS is SOLAR + PCM + Inverter + Solar Thermal.  The compressor compacts vaporized refrigerant (ammonia) to high pressure and high temperature to raise the boiling point of refrigerant. The condenser then liquefies the vaporized refrigerant to high-pressure and high-temperature state. The process also enables heat rejection. The condensate from the condenser is collected in a reservoir and allowed to pass through an expansion valve where the pressure and temperature further decrease. The low-pressure liquid refrigerant then passes through the refrigerated space where the heat of hot air of refrigerated space starts evaporating the liquid refrigerant. This results in cooling by decreasing the amount of heat in the atmosphere. Blowers circulate the chilled air within the storage unit (for fruits and vegetables).
Applications	Farm-Gate Micro-Enterprises
Business Model	Manufacturing of refrigerators, direct sales and last mile distribution of the products is managed by the in-house team of GESS.
Pictures	 

7 Company Landscape

Steca
A KATEK Brand

Company	Steca is a leading supplier of products for the solar electronics industry. It follows international standard for the regulation and control of solar energy systems. Steca is working in three market segments: PV grid connected products, PV off-grid products, and solar thermal products. Steca focuses on made-to-measure solutions for the effective utilisation of solar radiation.
Technology	Steca Solar refrigerators operate on 12 V / 24 V automatic voltage detection battery bank (Lead or Lithium ion). The system is an electronic control system which includes data logger and automatic power cut-off mechanism. Steca uses climate-friendly refrigerant and energy-efficient LED interior lamps in the refrigerators. 
Applications	Micro-Enterprise Healthcare
Business Model	Manufacturing of refrigerators, direct sales and last mile distribution of the products is handled by the in-house team of Steca.
Pictures	 

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Annexure B: List of Stakeholders Consulted

	Development Partners and Think Tanks
1	BASE Energy
2	CLASP
3	Clean Energy Access Network (CLEAN)
4	Energy Savings Trust
5	GIZ
6	Humboldt State University
7	International Finance Corporation (IFC)
8	Rockefeller Foundation
9	SELCO Foundation
10	Shell Foundation
11	Signify
12	The Energy and Resources Institute (TERI)
13	United Nations Development Program (UNDP)

	Financiers
14	Acumen
15	Aditya Birla Capital
16	Meghraj Capital
17	Vedika Capital

	Non-Governmental Organisations
18	Aga Khan Rural Support Programme
19	Self-Reliant Initiatives through Joint Action (SRIJAN)
20	Society for Technology Application for Rural Transformation (START)
21	Society for Upliftment of People with People's Organisation and Rural Technology (SUPPORT)

	Companies/ Customers
22	CoolCrop
23	Cygni
24	d.Light
25	Devidayal Solar Solutions Private Limited
26	Ecozen Solutions
27	Fourth Partner
28	Green Light Planet
29	Inficold India Pvt Ltd
30	Kaer

Annexure B: List of Stakeholders Consulted

Companies/ Customers	
31	Kpay
32	NIWA
33	Phocos
34	Pluss Advanced Technologies Private Limited (PLUSS)
35	Promethean Power System
36	Simpa Energy India Private Limited
37	Sinfin
38	Smart Joules
39	Smart Power India
40	Kisan Club
41	Tan 90
42	Thermal Energy Service Solutions Private Limited (TESSOL)

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