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Government of India

CoolCrop

Affordable Access to Solar Powered Cold Storages:

Piloted Business Case on 'Cooling as a Service' with Smallholder Apple Farmers in Himachal Pradesh

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Registered offices
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Green Innovation Centres for the Agriculture and Food Sector - India
No. 38/43, First Floor, 10 A Main Road, Fifth Cross
Block 1, Jayanagar
Bengaluru – 560 011, India
T (India) +91 80 46664000 (Extn. 6000)

E greeninnovationcentreindia@giz.de
I www.giz.de/en

Programme:
Green Innovation Centres for the Agriculture and Food Sector - India

Institutional partner:
Mission for Integrated Development of Horticulture,
Ministry of Agriculture & Farmers Welfare,
224, Krishi Bhawan, Dr. Rajendra Prasad Road,
New Delhi - 110001, India

Implementation partner:
Coolcrop Technologies Pvt. Ltd.
Annapurna, Shastri Pol, Raopura,
Vadodara - 390001, India

Assignment supervisors from GIZ:
Ms Regina Sanchez Sosa y Hernandez
Project Director
greeninnovationcentreindia@giz.de

Technical Team:
Sashi Kumar, Project Managers, Apple Value Chain, GIZ
Umesh Kumar, Agriculture Advisor, GIZ
Manish Kumar, Agriculture Advisor, GIZ
Apurva Sood, Junior Agriculture Advisor, GIZ

Text and Layout:
Puneet Bansal, Junior Knowledge Management Advisor, GIZ

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Piloted Business Case on 'Cooling as a Service' with Smallholder Apple Farmers in Himachal Pradesh

Above and Front Cover: Solar powered cold storage installed in Siladesh village, Shimla

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CaaS	Cooling as a Service
CVAS	Chuwara Valley Apple Society
BASE	Basel Agency for Sustainable Energy
EMPA	Swiss Federal Laboratories for Materials Science and Technology
GHG	Greenhouse Gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GIC	Green Innovation Centre for the Agriculture and Food Sector
iDPP	Integrated Development Partnerships with the Private sector
ISFPC	Inner Saraj Farmer Producer Company Limited
MoA&FW	Ministry of Agriculture & Farmers Welfare, Government of India
PHL	Post Harvest Losses
YVCCA	Your Virtual Cold Chain Assistant

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01. INTRODUCTION

The Green Innovation Centre for the Agriculture and Food Sector (GIC) - India is being implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Gmbh, on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), in partnership with the Ministry of Agriculture & Farmers Welfare (MoA&FW). GIC India has been working with the tomato and potato value chains in Andhra Pradesh, Maharashtra, and Karnataka, and the apple value chain in Himachal Pradesh. Its work in Himachal Pradesh is supported by the Department of Horticulture, Government of Himachal Pradesh. The GIC project is being implemented in Apple Value Chain since 2018 with a focus on increasing farmers income, productivity, and sustainable agriculture practices.

This document shares the experience of piloting an innovative business model for providing access to solar powered cold storages for smallholder apple farmers. This pilot was implemented in Shimla and Kullu district of Himachal Pradesh from the year 2021 onwards under the partnership model of integrated development of public private partnership (idpp) with CoolCrop Technologies.

CoolCrop Technologies Pvt ltd is a social enterprise which works with farmers and other stakeholders to develop sustainable preservation and processing solutions across the agricultural supply chain. They promote three products – a solar powered cold storage, a crop management system for the cold storage, and a predictive market analysis tool.

This document is a first-hand documentation of the pilot to inform the learnings to tech-businesses, Government, Development organisations, Farmers, and other stakeholders for further replication. The business model is evolved to address challenges of the smallholder apple farmers of Himachal Pradesh so as (a) to enable affordable access to on farm clean cooling technologies to mitigate the post-harvest loss prevalent at farm gate (b) to establish fair and remunerative market linkages (c) to create more value per kilograms of crop near farm gates by enabling access to energy efficient primary & secondary processing technologies. In summary, this intervention is designed to provide affordable access to productive assets, improve market linkages, and maximize storage efficiency, while minimising the carbon footprint.

Solar powered cold storages provide a solution to multiple problems. Through prolonging the shelf life of the produce, cold storages provide opportunities to sell the produce at a later date avoiding glut and distress selling by farmers. It additionally cushions the farmers in times of supply chain shocks. Using solar power provides opportunity for additional revenue through net metering of the solar PV modules.

The *'Cooling as a Service'* (CaaS) business model brings the cold chain infrastructure to the doorsteps of smallholder farmer, providing affordable access to cold storages. This enables the farmers to store the apple crop beyond the harvest season and take advantage of the better prices later. Providing cold storages as a service, which are owned and maintained by a separate business entity, helps in ensuring financial affordability for farmers as well as sustainability of the intervention. Operation using solar power avoids negative environmental impacts. This approach thus offers multi-dimensional benefits, which can be of interest to farmers, businesses, non-profits, and the Government.

This model makes the technology economically viable for both farmers as a user and businesses as a provider. The upfront costs, investments, and maintenance costs are borne by the tech-business, who provide the cold storage to the farmers at or near farm gate. The farmers only pay a user fee for the stored produce. The pricing strategy for the fee is based on the investment by the tech business as well as the additional value generated by the cold storage for the farmer. Integration of value-added services such as sorting and grading, and market linkages, further enhance value for the farmers.

This model fills the gap in the existing landscape where cold storages, solar or conventional, have a very limited presence. This is even more so in the case of hilly terrains of Himachal Pradesh. Further, tapping into solar energy is a costlier affair than conventional cold storages, putting it further out of the reach of farmers. By involving private players to fill the gap in rural infrastructure and based on ground level needs assessment and clustering of cold storages, this model makes this crucial infrastructure viable.

Catering to the needs of smallholder farmers, the on-farm cold storage and value-added services translate into better incomes. They also increase the farmer's bargaining power, who currently depend on large private cold storage / control atmosphere owners for storing and selling their produce in off season. Further support by the service provider for market linkage through an app – *Your Virtual Cold Chain Assistant* (YVCCA), holds promising future possibilities. Further research is ongoing to formulate ways in which this technology and model can help in value addition.

The cold storage also plays a significant role in reduction of post-harvest losses at the farmgate. This reduction along with solarisation lead to avoided greenhouse gas (GHG) emissions, which contributes to climate change mitigation. The cold storage themselves also contribute to resilience to supply chain shocks.

Currently, regional scaling up efforts have recognised two farmer producer companies in Shimla and Kullu districts, who are interested in installing more such distributed cold storages, through unlocking additional finance for upfront investment costs. A concentration of these in within a geographical unit is expected to attract buyers to the farmgate.
While this promising technology holds multi-dimensional social, economic, and environmental benefits, our experience has shown that the most important step in its implementation are successful partnerships between public and private players. These players span the agriculture, energy,

supply chain, and finance domains. Establishing successful partnerships between farmers and farmer groups, tech-businesses, regional and local government, banking and insurance institutions, transportation networks, and power distribution companies, can manifest into necessary institutional and framework conditions, unlock blended modes of finance, and deliver efficient and sustainable service to the end users.■

BOX 1: Systemic Issues in Indian Agriculture

The month of August 2023 saw images of destruction due to landslides and floods in the state of Himachal Pradesh splashed across the Indian national media. This natural disaster has become increasingly frequent in past two decades. Each time, it causes disruption of transportation networks and supply chains across the state. In 2023, it particularly affected the Apple cultivators of the region, and the speculation on the impact of this calamity on the crop and prices was rife.

Apart from natural calamities and disruption of supply chains, the other common event when smallholder farmers find themselves in media spotlight is when they dump their crops by the roadside. This happens often, when the farmers are offered low prices that fail to cover their investments in inputs, transportation, and storage. These scenarios highlight some systemic interconnected issues in the agriculture sector – sensitivity of supply chains to external shocks, huge post-harvest losses, vulnerability of farmers, and a general lack of rural infrastructure.


Monsoon 2023: Himachal Pradesh Records Highest Number of Floods and Rain Events

According to data from the state administration, Himachal Pradesh has already experienced 180 instances of landslides and flash flooding.

By Newsd

Published on: Mon 02nd October 2023, 12:23 AM

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Figure 1: News reports on intensity of floods in Himachal Pradesh in 2023 (newsd.com)

02. BACKGROUND

- *Despite the important role of apple value chain in Himachal Pradesh, smallholder farmers have limited access to cold storages. This in turn impacts their linkages to and position in the market. Significant post-harvest losses pose the other challenge in this value chain.*
- *Access to cold chains can mitigate these two challenges. The need to upscale cold chain infrastructure is imminent, with potential to tap into the horticulture sector. However, the accompanying burgeoning energy demand currently can only be catered to by fossil fuels.*
- *Distributed renewable energy solutions in this context present an alternative with social and environmental benefits. They however need to be made economically viable for adoption and upscaling.*

2.1 Apple Production in Himachal Pradesh

Apple is a major crop for the economy of Himachal Pradesh. A large population is dependent on the crop for their livelihood. However, lack of access to cold storage infrastructure at the farmgate is responsible for post-harvest losses which result in significant economic losses.

Himachal Pradesh is the second largest apple producer in India and approximately 90% of its produce is sold in the domestic market. In 2021-22, Himachal Pradesh produced 612,000 metric tonnes (MT) of apples in an area of 115,000 Ha (DoA&FW, 2023). The Himachal Pradesh apple economy is worth nearly INR 5000 Crore, and apple constitutes more than 80% of the total fruit produced here (HPHDS, 2023). This makes apple as the most important fruit crop in the State, constituting approximately 48.8% of the total area under fruit crops (DoA&FW, 2023).

In the apple value chain, significant post-harvest losses occur at the farmgate itself immediately after the harvest due to a lack of proper near farm cold storage infrastructure and other supply chain bottlenecks. Apples generally do well in storage, packing, and at retail if properly stored at right temperatures, but can suffer catastrophic losses in the field, during transportation, and at grading, where water loss, firmness and bruises are all too common.

It is estimated that Himachal Pradesh loses nearly 15-20% of the apples produced as post-harvest losses (PHL) due to multiple handling points and poor near farm infrastructure especially in higher altitudes above 6000 feet above Mean Sea Level. The reason is that in high altitude terrains, the access to infrastructure and other facilities for better post-harvest management is scant and poor, including the last mile electricity grid and transportation connectivity.

2.2 Key Challenges for Farmers in the Apple Value Chain

Majority of apple farmers in Himachal Pradesh are smallholders. This limits their bargaining and price negotiation opportunities in the market, as well as access to cold storage infrastructure. As a result, they do not get the full economic value of their crop.

Smallholder farming landscape: As per the Agriculture Census 2015-16, the average farm holding size in Himachal Pradesh is 0.95 Ha. Small and marginal farmers own 88.85% of the total holdings (a farm plot of 0-2 Ha), semi–medium and medium farmers own approximately 10.85% of the total holdings (farm plot size of 2-10 Ha), and large farmers own about 0.30% (land holding of 10 Ha and above) (MoA&FW, 2019). The small land holding combined with lower price realization at farm gates not only reduces the farmer's income but also affects their capacity to invest in productive-use technologies to improve on farm storage efficiency or boost productivity.

Long term cold storage and controlled atmosphere (CA) store facilities are mostly owned by private businesses or market intermediaries: The apple season in Himachal runs from Mid-July to late October. The state has a storage capacity of more than 65,000 MT of fruits in more than 20 CA and cold stores run by the government and the private sector. A part of the total production of apples is stored in these facilities to avoid distress sale or glut in the market, and to sell the fruit in the off-season. Storage usually starts in the state in September. Most of the CA/cold stores in the state are privately-run, while the HPMC, a State Government undertaking, runs five CA stores and two cold stores. The farmer organizations believe that, as the season progresses, the private store owners procure the crop directly from the farmers at increasingly lower rates. Since the apples are harvested sequentially from lower to higher elevations, this leaves the framers in the higher altitudes at a disadvantage from getting a fair price despite their better-quality produce. Many farmer groups allege that the private CA stores resort to bulk buying to distort prices in the entire market with this kind of progressively low-price buying strategy as the season advances.

"From a farmers perspective the 'market' linkages in the apple value chain tend to reduce rewards and/or increase market risks for small producers..."

Non remunerative price realization at farm gate: As per the responses in a survey of small apple farmers carried out by GIC India, Coolcrop Technologies and BASE (Evangelista, 2022), bulk of the harvest is sold at Rs 30-40 per kg, which does not even cover the costs of farming, while the retail prices are always upwards of Rs 150/Kg. For every kilogram of apple that sells between the range of Rs 150-200, the farmers receive a mere Rs 40. Thus, the retailers accrue a disproportionate share of the profits.

Opaque quality criteria imposed by the intermediaries further drives down price realization at farmgate: Both the private CA store owners and the market intermediaries procure apples based on various criteria, of which one is colour. Apples have three colour categories — 80 to 100% red, 60 to 80% red, and below 60% red. Since the farmers don't have access to sorting and grading technologies, they rely on visual or manual procedures affecting their bargaining power. Farmer groups complain that they do not receive the fair price as per the quality of their produce. Private store owners are able to negotiate lower prices citing the colour criteria.

High input costs further suppress the farmers profitability: The farmers bear the brunt of high input costs, which according to the surveyed farmers have increased by more than 50%. They feel that the procurement price has not gone up proportionately to cover these high input costs.

From a farmers perspective the 'market' linkages in the apple value chain tend to reduce rewards and/or increase market risks for small producers and have the common characteristics as prevalent across all the horticulture value chains of India , ranging from: high price uncertainty which is negotiated at each exchange; unreliable market information from buyers; no/low rewards for quality; lack of traceability, which is a precondition for certification to food safety and sustainability standards.

2.3 Need and Potential of Cold Chain Infrastructure in India

There is a felt need for cold chain in horticulture supply chains, with immense potential for its development and upscaling in the next decade. However, this will increase demand for energy, most of which is catered to by fossil fuels.

Cold storages preserve the quality and shelf life of the produce, thus making possible new opportunities for marketing. The COVID-19 pandemic has also exposed the need for sustainable and resilient supply chains, especially for perishable commodities. Investment in cold chain holds the promise to develop more resilient chains and minimising disruptions due to future shocks.

The potential of cold storage development is indicated by India Cooling

Action Plan's estimation that by 2027-28, India would have developed approximately 55,000 packhouses against the 500 in 2019 (MoEFCC, 2019). A report by World Bank and Alliance for Energy Efficient Economy states that despite this need and potential, the actual trajectory of packhouse infrastructure development may vary depending on several factors such as market dynamics, consumer demand, and uptake of government policies (AEEE, 2022). Thus, much of the investment for meeting the demand for packhouses is yet to be made. According to the report, this presents an excellent opportunity for early action to ensure that packhouse infrastructure development happens in a resource-efficient and sustainable manner. Further, while the cold-chain for frozen products is comparatively well developed, being primarily industry driven, the significant part of infrastructure for handling of fresh produce (fruits and vegetables) is yet to come (MoEFCC, 2019).

"This ongoing expansion is expected to consume 7.8 GW of electric power. Currently this energy demand can only be catered to by fossil fuels."

This expansion will however pose new challenges. In 2016, with an installed capacity of 30,000 MT, cold storages consumed 1.2 GW or 0.5% of the installed electrical capacity, catering to 6.7% of the gross produce. Considering a need for 20% coverage of the produce requiring cold storages, the installed capacity of cold chains needs to scale up to 200 million MT by 2030. This ongoing expansion is expected to consume 7.8 GW of electric power (Bhatt, 2016). Currently this energy demand can only be catered to by fossil fuels. In view of India's commitments under the Paris Agreement, cold chains need to explore and develop renewable sources of energy such as solar.

2.4 Distributed Renewable Energy in Indian Agriculture

Renewable energy solutions in agriculture can mitigate emissions, with significant potential in cold chain infrastructure. Distributed renewable energy technology can have a greater infiltration and reach to smallholder farmers. The challenge, however, is economic viability, technology adoption, and upscaling.

As per the Third Biennial Update Report submitted to the United Nations Framework Convention on Climate Change by India, agriculture is responsible for about 14% of economy-wide GHG emissions in the country (MoEFCC, 2021). While there is a clear need to mitigate these emissions in the context of climate change, this needs to be balanced with the needs of development of rural infrastructure and mechanisation. A more pressing need in this context is to adapt and develop resilience to impacts of climate change, which will range from extreme weather events and changing rainfall and temperature patters to increased incidence of pests and diseases. Since majority of the farmers are smallholders, it renders them even more vulnerable with reduced adaptive capacities. Further, despite the commendable gains made in the last-mile connectivity in rural electrification, reliable power supply in rural areas can often be erratic.

"The challenge, despite availability of technological fixes, remains in large upfront investments, their large-scale adoption, and scaling."

Distributed renewable energy, especially solar, can fill this gap in rural energy access, while avoiding GHG emissions and contributing to climate change mitigation. These solutions can additionally enhance farmer incomes and increase efficiency in supply chains by cutting post-harvest losses.

The Government of India is implementing several programs to encourage use of renewable energy. Indian Renewable Energy Development Agency provides solar subsidies and loans for various solutions through the National Bank for Agriculture and Rural Development. Pradhan Mantri – KUSUM encourages various solar-powered solutions specifically for agriculture, such as water pumps and small solar power plants.

The challenge, despite availability of technological fixes, remains in their need for large upfront investments, adoption, and scaling.

Figure 2: A typical solar powered cold storage implemented in tomato and potato value chains

03. ENABLING SOLAR POWERED COLD STORAGES TO ADDRESS CHALLENGES IN THE APPLE VALUE CHAIN

- *The intervention encourages smaller, customisable, and distributed cold storages powered by solar energy, located at or near farmgate. Distribution and location of cold storages depends on several geographic and economic factors.*
- *Based on 'Cooling as a Service' Business Model, all upfront investments, including installation and maintenance costs, are borne by a technology-cum-service provider. The farmers only pay a user fee for the stored produce. The pricing strategy should be such that it is viable for both the technology provider and the farmer.*
- *The need to manage post-harvest losses presents an opportunity for uptake and upscaling.*

Deployment of climate-friendly cooling technologies along with energy efficient packing and grading facilities is limited at the farm level due to the smallholder farmers' inability to afford high-upfront costs, limited financing options, and know-how. Enabling affordable access to near-farm or at farmgate modular cold storage and processing facilities to collectively address these pain points is critical to address some of the issues of smallholder farmers, provide access to energy, and minimise post-harvest losses. These facilities can give farmers an option to sell the produce at the right price at the right time instead of immediate or distress liquidation of their produce after harvest.

The piloted intervention demonstrated access to solar powered cold storages through an innovative business model that provides 'Cooling as a Service'. The need for smallholder farmers to be linked with cold storages is a pressing one, in view of developing profitable market linkages, resilient supply chains, and remunerative price realisation. The model allows farmers to store their produce till the realisation of attractive prices in the market, or when it is not possible to access markets due to natural calamities. In case of perishable goods such as apples, the latter point is already illustrated well during the Himachal floods of 2023 and COVID-19 pandemic. Further, distributed cold stores can reduce transportation costs and increase bargaining power of farmers.

Additionally, the intervention also enables solarization of the basic primary processing facilities like sorting, grading, and packing solution. It allows smallholders to access these facilities while only paying for the food they store (per kg-day) in the cold rooms, avoiding any upfront investment on their part.

3.1 Introduction to Solar Powered Cold Storages

Solar powered distributed cold storages reduce transportation, increase penetration, and reduce the desperate sales by the farmers. The piloted technology is customisable as per the local context and needs. Connections to the electricity grid provide both a backup source of power and a potential stream of revenue through future net metering. However, rightly sizing and locating the cold storages based on local geographic and economic criteria is important to maintain viability.

Rather than enabling large cold storages, the pilot intervention focuses on smaller distributed cold stores. These present many advantages against traditional large cold storages. Decentralisation reduces transportation, increases penetration and reach, and increases farmer's decision-making capacity against large cold stores. Solar powered cold storages, apart from the immediately apparent environmental benefit of avoided GHG emissions, can also offer an alternative energy solution in remote and isolated locations, as well as generate additional streams of revenue for

Figure 3: Schematic representation of the solar-powered cold storage

farmers who can sell surplus energy to the grid through net-metering of solar-PV modules.

The technological specifications of the solar cold storage deployed under this pilot are given in Table 1. The piloted technology is customisable as per location-specific and user-specific needs, with deployable capacities of 5-20 MT. As shown in figure 3, the cold storage is hybrid, connected to both solar panel, electric grid, as well as an electrical storage system. This allows surplus solar-generated electricity to be stored which can be utilised in unfavourable weather or sold to the grid. The grid at the same time acts as a back-up during prolonged periods of lack of sunshine disabling solar energy generation.

For the technology to be viable, it is important that geographic and economic factors are considered while locating the cold stores. Availability of optimum year-round sunlight, land, and availability of water for construction (especially in hilly terrains), access to roads and power lines, and proximity to markets are important geographic factors. Whereas crop calendar such that optimal crop mix ensures year-

Specifications	Values / Description
Type	Dual Chamber Solar powered cold storage
External dimensions	34ft X 13.5ft platform
Internal capacity	1500 CFT
	2 chambers with internal volume of 750 CFT each
Storage capacity	Minimum 5 MT per chamber
Temperature Range, °C	4 - 15 °C
Pull down desired time	18 hours
No. of door openings / day	2 opening per 6 hours for 30 sec
Wall and ceiling insulation & thickness	100 mm Poly Urethane Foam
Floor insulation and thickness	100 mm Poly Urethane Foam + Anti-skid
Door type	100mm Poly Urethane Foam
Door curtain	PVC curtain before the door to reduce Heat infiltration on door opening
Ambient temperature	40 °C
Back up duration	24-30 hours (non-door opening & 4.5 kWh/m2-day global horizontal irradiance)
Power Source	
Photovoltaic panels type	Polycrystalline/Monocrystalline
Size	12 kWp
Solar charge controller	MPPT
Electrical Batteries (Auxiliary Power)	As per auxiliary load requirement for mentioned autonomy. (Auxiliary loads such as fans, lights,valves & control system). The VRLA/T-Gel.
	Batteries should be used.
Mounting Structure	The mounting structure should be designed over the roof area of cold storage or super structure should be designed.
Alternative Power input facility	Grid & DG.
Condensing unit	Condensing unit for -5°C evaporating and 40°C condensing temperatures
Evaporator unit	Minimum 2 Nos. of Fans and minimum air through of 750CFM each
Refrigerant	R407c/R407f
Charging duration	5 to 7 hrs. (ambient temperature dependent)
Thermal storage medium	Water / other
Cooling storage capacity	Minimum 100 MJ enough to precool 1MT from 30 to 10 °C primarily on thermal storage system
Heat transfer medium from thermal storage to the evaporator unit of cold storage	Refrigerant (R134a/R404a)
Thermal storage capacity indication	Linear with minimum 4 graduations between maximum and minimum thermal cooling capacity
Self-leakage from thermal storage	Maximum 300 Watt at the ambient temperature of 40 °C
Thermal storage configuration	Completely stops providing cooling in the cold storage when temperature of cold storage is achieved to the desired levels.

Table 1: Specifications of deployed solar powered cold storages

round usability of cold storage, availability of marketable surplus, and farmer's ability to pay are necessary economic factors. Rightly sizing and solarising near-farm and farmgate cold storages not only de-risks the long-term system operating cost, but the surplus energy in lean crop season can be metered back to the grid, thereby improving last mile grid power quality and reliability.

3.2 Affordable Access though Cooling as a Service Business Model

CaaS business model allows farmers to only pay a user fee for using the cold storage rather than having to invest and own the infrastructure. All capital investment is borne by the technology-cum-service provider. The pricing strategy of the user fee, as well as the financing structure of the investment, will determine the economic viability of the intervention. Additional and potential revenue streams currently being developed are through value addition and net metering. To make the model work, an initial needs assessment is crucial for customisation to local needs, rightly sizing and locating the storages in clusters, and correct pricing. Accountability contracts are undertaken with user farmers. In future, bridge finance for the service provider is essential to meet the capital expenditure.

The Model

The efforts to increase farmer's access to cold storages have been going for a while. Multiple ministries of the Government of India have released schemes, such as Mission for Integrated Development of Horticulture (MIDH) by MoA&FW, Pradhan Mantri Kisan SAMPADA Yojana by the Ministry of Food Processing Industries, and the financial assistance scheme of Agricultural and Processed Food Products Export Development Authority under the Ministry of Commerce and Industry (MoCI) (AEEE, 2022). Many private sector and development organisations have been working independently or in coordination with these ministries to promote solar and conventional cold storages. However, the challenge remains to make them economically viable for farmers and businesses alike, to increase their adoption, and ensure their sustainability.

Table 2: BUSINESS CANVAS for the Caas Model

Key Activities

- Customer service including transportation, payment options, technical support
- Establishment of efficient and reliable distribution channel to transport apples from farms to the cold storage facility, and from the facility to the market.
- Develop flexible payment options and financing models to cater to the needs of small-scale producers.
- Explore new revenue streams by offering value-added services such as sorting, grading, and packaging of apples.

Key Stakeholders

- Cold storage manufacturers
- Solar panel suppliers
- Finance institutions
- Electrical engineers
- Installation services
- Maintenance and repair services
- Transportation services

Key Resources

- Physical infrastructure
- Technology and equipment
- Skilled workforce
- Transportation and Logistics
- Financial resources
- Partnerships and collaborations

Customer Segments

Smallholder apple producers/ Farmer cooperatives: Allows selling apples at a higher price (off-season), negotiate better prices and earn more income, while also reducing the risk of spoilage and waste.

Processors, Marketers, Buyers and Retailers: consistent and high-quality supply of apples, reducing the risk of shortages and price spikes.

Channels

- CaaS for farmer cooperatives involves a third-party service provider who owns and operates the cooling infrastructure and charges a fee for its use, either on a pay-per-use or subscription basis

Customer Relationships

- Apple producers/ farmer cooperatives: Access to cooling technologies as a service for smallholder farmers via CaaS
- Downstream - Processors and Marketers: Transactional selling the apples at an agreed-upon price (fixed contracts)

Value Proposition

- Strategically located near major apple producing areas minimizes transportation costs
- Allows to sell at a later point in time securing higher prices on the market
- Reduces post-harvest losses and extends shelf life of apples by creating optimal storage conditions, including temperature and humidity control
- Solarizing key energy services reducing the carbon foot print of key operations

Cost Structure

For Cooperatives

- Fee for quantity of apples stored

For Cold Storage Service Provider

- Capital costs for building and maintaining the cold storage facility,
- Operating costs such as electricity, water, and labor costs
- Transportation costs for moving the apples to and from the cold storage
- The technical expertise and management required to operate
- Developing and maintaining relationships with smallholder farmers, buyers, and other stakeholders in the apple value chain.

Revenue Streams

For Cooperatives

- Preservation of the quality and shelf life of apples,
- Reduction of post-harvest losses
- Enabling to sell their produce at a higher price at a later date when market conditions are favorable

For Cold Storage Service Provider

- Storage fees
- Transportation fees
- Fees for additional services such as sorting and grading

The CaaS model presents an approach towards this objective. It provides access to cooling technologies as a service for smallholder farmers, who may not have the resources to invest in such technologies themselves. This model involves a third-party service provider who owns and operates the cooling infrastructure and charges a fee for its use, either on a pay-per-use or subscription basis. This approach can reduce the upfront costs for farmers. Simply put, farmers who store their produce in the cold storage and only pay a usage fee per unit. Installation and maintenance costs, and financial risks are borne by the technology provider. This model provides farmers with access to energy-efficient cooling technologies, which can help to reduce post-harvest losses and increase the value of their produce.

Revenue streams for the cold storage provider include storage fees, transportation fees, and fees for additional services such as sorting and grading. The fee charged to farmers is based on the total costs of installing, operating, maintaining, and financing the equipment. This fee is calculated as a percentage of the total revenue from the cost of the equipment, maintenance, electricity, leasing payments, and bank sale for the lease. Farmers pay for the value that the cold storage provides in terms of preserving the quality and shelf life of their apples, reducing post-harvest losses, and enabling them to sell their produce at a higher price later when market conditions are favorable.

It is estimated that the intervention can increase volumes by 25-30%, which otherwise would have been lost as PHL and value by 30% since quality is retained for longer duration.

In the long run, it is envisioned that the community collectives, such as local social enterprises, Farmer Producer Companies, or other such collective of users, will own the cold storages. The community owned cold storages can generate further revenue for its users through net metering for solar-PV once the project is handed over to them.

The Process

To operationalise the model, the cold storages are distributed in clusters, strategically located near production areas. Agreements are reached with willing farmers, who may be individual users, cooperatives, or even agribusinesses with a network of farmer suppliers. A need assessment helps in defining size and type of cold stores, as well as value added services. It is necessary that cold storages are located closely in clusters for facilitating efficient distribution and sale later, owing to the still largely informal channels of market linkage. Further, the idea is that buyers will come to the farmgate for purchasing apples, and closely located cold storages can help fulfil large and bulk orders.

Figure 4: Pricing Strategy for Economic Sustainability of the Model

The need assessment will also aid in calculating service fee to be paid by the farmers. This fee can be charged in multiple ways – based on type of produce, projected volumes, weight or number of crates, or even long-term flat rates. The service provider shall install and maintain the equipment and infrastructure, recovering the costs through periodic payments made by the farmers, farmer groups or FPCs. The service provides an opportunity to develop small-scale rural cooling hubs that can be distributed around high-density small-scale production areas. These can be made available to local producers and organizations for harvest periods, leased for short periods, and complemented by a range of value-added services.

As the cold stores are with 10-20 MT capacity relatively small, a single farmer could theoretically fill the cold store with her crop. However, the reality is that due to the high upfront costs of inputs and equipment, farmers in HP are forced to sell about 70% of their produce immediately after harvest and can only store about 30%, which equates to about 300-400 crates. As a consequence, groups of 3-10 farmers have to join together to utilize the cold storage facilities to full capacity. The idea is that accountability contracts are undertaken between the storage provider and Farmer Producer Companies/ Cooperatives who themselves decide which of their member farmer interest groups will receive a storage facility. A direct channel with farmer groups and/ or cooperatives is established via the CaaS model. The scheme overcomes the main issue of ability to pay as small-scale farmers have limited financial resources.

The major geographical challenge is that due to poor accessibility and road infrastructure in HP, the storage providers are exposed to high operational costs. The management and maintenance of cold storage facilities is currently seen as the biggest hurdle to economic sustainability. To counteract these hurdles, the long-term concept therefore envisages that the cold storage facilities are geographically distributed in a clustered manner. This means, however, that only after the innovation has been scaled up and widely disseminated is its operation economically viable resulting in the requirement of large upfront capital risks or need of subsidies beforehand.

Value Addition

The combination of value addition alongside cold storage intends to aid smallholder farmers in fetching better prices for their produce. This is not just beneficial to farmers, but providing this service is also indirectly beneficial to the technology providers in the longer term, as it would enhance farmers ability to pay an optimum user fee periodically. These are discussed in detail in Chapter 4.

BOX 2: Installation of Solar-powered cold storages in Shimla and Kullu Districts

The pilot intervention installed 4 cold storages as detailed in Table 3. These were installed in four villages across Shimla and Kullu districts of Himachal Pradesh for piloting the model.

There are two variants of cold storages deployed:

- A 10 MT variant with a capacity to store up to 500-600 crates of apples, with each crate holding approximately 20 kg of apples.
- A 20 MT variant with a capacity to store up to 1000-1200 crates of apples, with each crate holding approximately 20 kg of apples.

Performance of these cold storages on various parameters is captured in Chapter 5.

Figure 5: A 20 MT Cold Store powered by 20 KW Solar PV System at Siladesh, Shimla District

Figure 6: An 8 MT Cold Store powered by an 8 KW Solar PV System at Andhra Village, Shimla District

Sr No.	Name of the Farmer	FPC Affiliation	Village	Block	District	Storage Capacity (MT)	Solar PV (kW)
1	Birendra Bashata	CVAS	Siladesh	Chirgaon	Shimla	20	20
2	Anil Sharma	CVAS	Andhra	Chirgaon	Shimla	10	8
3	Bagh Singh	ISFPC	Pahli	Banjar	Kullu	12	8
4	Kishan Singh	ISFPC	Chatradala	Sainj	Kullu	8	8

Table 3: Details of installed solar powered cold storages

Testimonials

"Modular and solar powered cold storage are the sustainable solutions of the future for small apple growers"

– Dr. Kushal Mehta, DoH

"Renewable Energy technologies are very new to our valley. If such technologies are installed at Krishi Vigyan Kendras, it will encourage more farmers to adopt it."

– Dr. Narendra Kaith, Director, KVK

"The solar powered cold storage will help us a lot and I hope that every village has one or two such facilities in the future to avoid the market glut."

– Mr. Bashata (apple farmer)

"The CVA farmers are consistently increasing apple productivity and there is immediate demand for farm gate cold storage. We will aim for one cold storage at each panchayat to overcome the sales done in desperation by our farmers."

– Mr. Sanjeev Thakur, President, CVAS

Financial Structure

The CaaS business model can be delivered in a financial structure as depicted in Figure 7 below. Cold room technology and solar energy service providers like CoolCrop Technologies own and maintain the systems, thereby covering the operational costs. This long-term commitment serves as an incentive for them to install the most energy-efficient equipment and perform high-quality maintenance. The farmers pay a user fee, whose structure and value is mutually agreed.

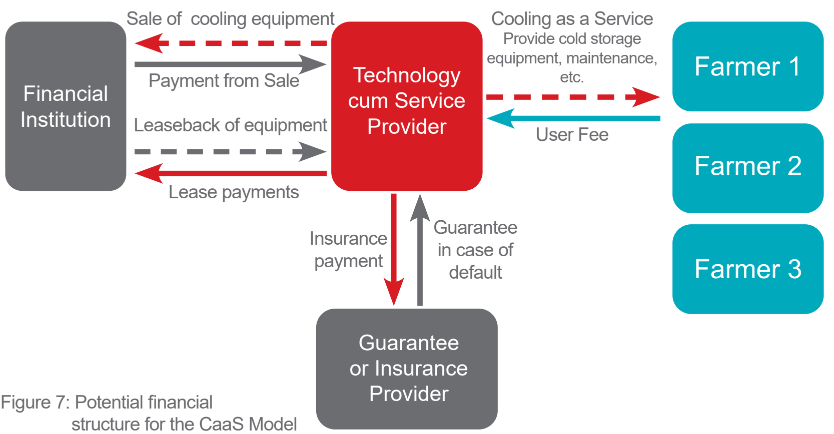

Figure 7: Potential financial structure for the CaaS Model

On the technology provider's end, a significant amount of money is required to invest in equipment. Currently, the financing could be ensured only via Integrated development partnerships with the private sector (iDPP) Model between GIZ India and CoolCrop Technologies Private Limited. In the future, bridge finance to meet the capital expenditure is essential. This could be done through a special purpose vehicle of the Government, through banking solutions, complimenting with existing subsidy schemes, or through blended finance.

One potential approach is a sale-leaseback model. In this approach, a bank or financial institution buys the equipment and then rents it back to the cooling system service provider (usually for a period that is no longer than the CaaS contract period). This transaction is called an asset-backed transaction, which means that an operating asset is leased to the technology provider for the duration of the contract. The contract between the technology provider and the customer (CaaS contract with farmers) is used as additional collateral, and a payment guarantee from an insurance company or an investment from a fund can protect the equipment provider from customer payment default. At the end of the contract, the ownership of the equipment returns to the technology provider.

Why a Business Model?

Most of the government policies and programs in place are back-ended, meaning farmers receive compensation only after they have made investments. This presents a major challenge for many farmers who lack access to upfront capital in the first place. This combined with challenges to tap into government schemes makes it very difficult for smallholders to develop decentralized cold storages. Hence, most of the groundwork to access finance, find viable technology, and install and maintain can be done by a business and technology provider. They facilitate access to technology while the farmer has to only pay a user fee. Only relying on government bodies to fill the large gap in the cold chain can take many decades. Participation of development institutions to facilitate partnerships between the farmers, private sector, financial institutions, and the government can fast track this process.

3.3 Need and Potential for Upscaling: Post Harvest Loss Management

About 10-11% of harvest is lost post-harvest along the apple value chain. These are an economic loss for both the producer and consumer, also impacting farmer's capacity to invest. Management of post-harvest losses presents an opportunity for scaling decentralised cold storages. Within Shimla and Kullu, two FPCs have committed to adopting the intervention based on the pilot.

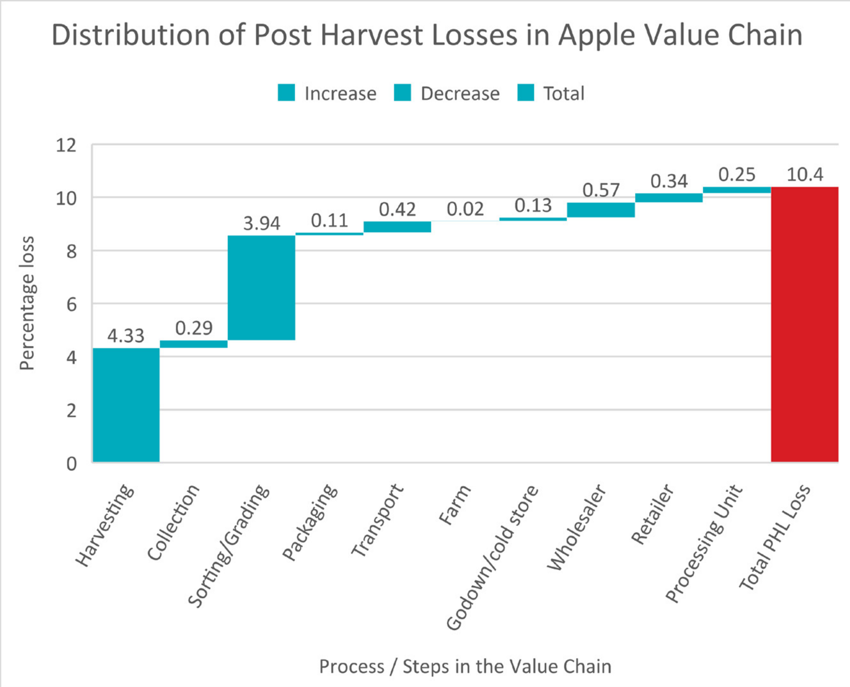

Figure 8: Per cent PHL along the apple value chain (Jha, Vishwakarma, Ahmad, & Dixit, 2016)

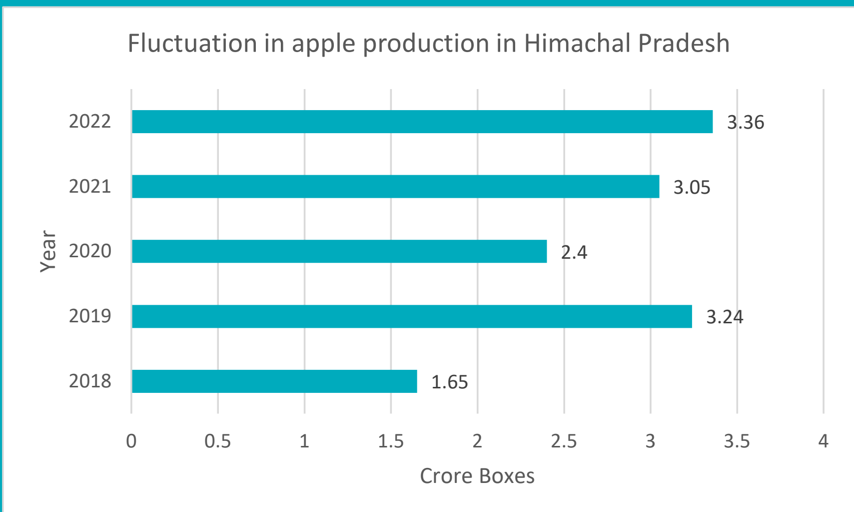

Figure 9: Fluctuation in Apple Production in HP (Crore Boxes)

In a study carried by CIPHET, Ludhiana the post-harvest losses in fruits In a study carried by ICAR – Central Institute of Post-Harvest Engineering and Technology (CIPHET), Ludhiana the post-harvest losses in fruits and vegetables in India were estimated to be worth US$2 Billion year on year (Jha, Vishwakarma, Ahmad, & Dixit, 2016). The CIPHET report estimates the post-harvest losses of apples to be between 10-11% along the value chain and can be valued at nearly INR 1600 Crores (US$200MN) on current prices. At a conservative estimate of 8% as the post-harvest loss in the Himachal Pradesh apple value chain, an estimated INR 400 Crores (~US$50 MN) are lost at the farm gate.

Post-harvest losses not only reduce the farmer's income, but also affect their capacity to invest negatively and disincentivises the farmers to grow more produce. Further, in a rapidly urbanizing marketplace, such huge loss of produce drives up the cost of food affecting the end consumer. Post harvest losses are not just loss of value, but also represent avoidable GHG Emissions and contribute to food insecurity.

Himachal Pradesh produces, on an average, nearly 30-35 million Boxes (Average 20-24 kg of apples/box) of apples every year. Erratic climate conditions have led to fluctuations in the production in last few years, even as the area under apple cultivation is increasing steadily, from 1,01,485 Ha in 2010 to 1,15,000 Ha in 2022.

There are generally 3 grades of quality for apple, namely A, B and C. A grade apples can fetch a significant price premium for their high-quality, generally averaging at INR 250-300 per kg and is determined by factors such as color, shape, appearance, visual appeal, and firmness. B and C grade apples however do not fetch equally high prices, and 70% of B and C grade produce goes for processing. The remaining 30% is often left idle post-harvest. To address this, the HP Marketing cooperation procures B and C grade apples to process into jam, jelly, and other products, catering to both small-scale and organized players.

Management of PHL, which is also a countrywide problem across many value chains, but especially for horticultural produce, presents an opportunity to scale up solar powered cold storages. The local success of the piloted intervention has already generated interest and is currently being locally scaled up in pilot locations.

Two Farmer Producer Companies, one each in Shimla and Kullu districts, have come forward to further adopt the cold storages. Chuwara Valley Apple Society (CVAS) in Shimla is a group of progressive apple growing farmers, while the Inner Saraj Farmer Producer Company Limited (ISFPC) is the second interested FPC in Kullu. Farmers in both FPCs grow apple as the major horticulture crop, alongside other fruit and agricultural produce, with significant marketable surpluses.■

04. INTEGRATING VALUE ADDED SERVICES

- *Integration of value-added services with cold storage furthers the service model, enhances farmer incomes, as well as their ability to pay the user fee. Two value added services have been introduced in this pilot.*
- *Sorting and grading operations, conventionally a part of the packhouses in the value chain, have been solarised. This avoids diesel consumption and brings these operations to the farmgate. It aids the farmers with right information on the quality of their produce during price negotiation with buyers.*
- *An app, which uses data and physis modelling, also supplies information on the quality and shelf life of produce pre and during cold storage conditions. It also allows remote operation of the cold storage. Further research to enhance the delivery of these services is underway, in collaboration with international research institutes.*

As mentioned earlier, value added services are an integral part of this intervention. There are two services offered initially, a solarised version of sorting and grading machinery, and a mobile app that helps in cold chain management as well as improves opportunities for market access.

These services, such as capacity building and assistance with market access, provide the support that can elevate small-scale production to a new level of competitiveness and sustainability. Each value chain service centre can serve 30-50 small-scale producers, with the potential to increase their overall net income by over 30% as a result of significant post-harvest loss reduction and increased quality standards. Cold-chain is not just about preservation, it also applies technology to stretch the marketable time of a perishable product, for a finite duration. In short, cold chain buys time, to temporarily extend the saleable life. The time in hand should be fruitfully utilized to expand market reach, especially for highly perishable fresh produce.

The app – YVCCA is being developed by CoolCrop Technologies in collaboration with BASE and EMPA. Established in 2001, Basel Agency for Sustainable Energy (BASE) is a Switzerland-based nonprofit that combines its multi-sectoral expertise to build bridges between sectors and actors at the nexus between climate solutions, finance, and international development. The Swiss Federal Laboratories for Materials Science and Technology (EMPA) is an interdisciplinary Swiss research institute for applied materials sciences and technology. It aims develop solutions for current problems facing industries and societies.

"...cold chain buys time, to temporarily extend the saleable life. The time in hand should be fruitfully utilized to expand market reach, especially for highly perishable fresh produce."

The idea going forward is to add as many value added service layers to increase the overall service value per kg.

4.1 Solarising the Sorting and Grading Operations

Sorting and grading operations are conventionally a part of the packhouses in the apple value chain and run on diesel. It is offered as a service in piloted cold storages and integrated with the solar modules. This saves diesel costs and avoids GHG emissions. Bringing this service at the farmgate aids the farmers with right information on the quality of their produce during price negotiation with buyers.

Most of the cold storage sites conventionally have preexisting sorting and grading facilities, independently installed by the farmers themselves or installed in an integrated packhouse concept. They are run on grid (70%) and diesel generator set (30%). Offering this solution along with the cold storage solarises its operations, reducing the diesel consumption by 50%. This is beneficial both economically and environmentally.

Further, bringing this service to the farmgate empowers farmers with information to negotiate correct prices for their produce, against the malpractices in the wholesale market described in Chapter 2, where buyers impose arbitrary quality criteria.

The diagram in figure 10 depicts the technical electrical design of the facility, showing how sorting and grading machinery can be solarised. By simply tapping into the same energy infrastructure as the cold storage, this service add multiple layers of benefit.

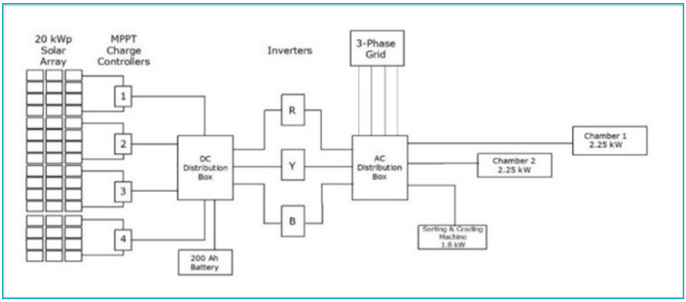

Figure 10: Connecting Sorting and Grading machinery to the Cold Storage System

4.2 Your Virtual Cold Chain Assistant

Your Virtual Coldchain Assistant (YVCCA) is an app to enable smallholders to optimise their decisions on produce and farm management. It allows the farmers to monitor the quality of their crops in real-time and provide access to tailored market intelligence to maximise their net profit, while leveraging the extended shelf life enabled by cooling.

The features provided by the app are detailed in Figure 11.

Figure 11: FEATURES OF YVCCA APP

1. Farm Produce Management and Prediction of Quality and Shelf Life of the Harvest

Powered by computervision, this app will assess the quality of the produce at harvest that is being stored in the cooling facility and predicts the remaining shelf life of the produce for the current cold storage conditions. It using physics-based modelling at this stage, fed by data on quality at harvest and the measured temperature and humidity in the storage room, based on wireless sensor data transfer.

2. Identification of Smallholder Farmers without Access to Cooling Facilities

The app will identify farmers that currently do not have access to cooling facilities and have the largest potential to adopt and implement our solution. This will be done with GIS techniques and machine learning models which leverage historical data on fresh-produce yields of smallholders in India, socio-economic indicators, satellite images, and distance from the grid and the market. We map these cross-disciplinary open data out in a GIS-based platform. This visualisation gives service providers and policy makers new ways for decision making in food supply chains.

3. Data Informed Remunerative Market Linkages

YVCCA provides remunerative market linkage strategy that connects the farmers to distant buyers via pricing data analytics to provide the farmers with suggestions on the best time and place to sell the produce to maximise their net profit. This prescriptive model utilises various data inputs on weather, market volume and location, satellite images, fresh-produce yields, hygrothermal cold-storage sensors, forecasted remaining shelf life of produce, and real-time market prices.

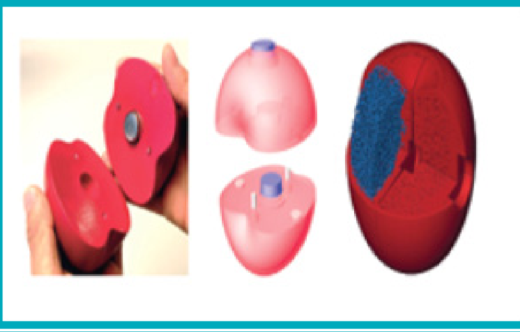

Figure 12: Diagrammatic representation of the Apple Simulator

4.3 Collaborative Academic Research & Business Application Development

As part of the pilot, GIZ and Coolcrop collaborated with BASE and EMPA to further research the strategies to improve value added services. They are summarised below.

Apple Simulator Deployment

Horticultural products are prone to high postharvest losses due to their perishability and susceptibility to drivers for food decay, including temperature. A narrow temperature window must typically be maintained to prevent accelerated decay and, at the same time, thermal damage, such as chilling injury. Food simulators help monitor postharvest supply chains, preventing temperature abuse in the cold chain, and optimizing refrigerated transport and storage. This simulator needs to be tailored for each commodity or cultivar to consider different physical properties influencing their thermal response.

A new apple simulator was developed and tested at the cold storage facility in at Siladesh, Himachal Pradesh to map the thermal distribution inside a cooling unit. By mimicking the real commodity's thermal response, one gains complementary insights compared to only monitoring air temperature. These food simulator's temperature data will help improve cold chain operations to achieve optimal and homogenous cooling and decrease postharvest losses.

Identifying Optimal Cold Storage Locations in Himachal Pradesh

An algorithm was developed to identify optimal cold room locations in Himachal Pradesh, India. This is done by adapting the algorithm behind a multi-layer, interactive map of India for site location that was previously released. The site location analysis is tailored to the requirements for a cold storage, with primary criteria being the distance to the electricity grid, distance to roads, altitude, as well as yearly apple production in MT at the block level.

Overlaying data meeting these criteria and set thresholds in different layers in a map narrows down the places where the cold rooms could be best set up. The thresholds and parameters in the algorithm can be modified such that the site identification can be performed for other constraints.■

BOX 3: Collaborative Academic Research

Himachal Pradesh is one of India's largest apple-producing states. We partnered with Coolcrop to deploy our biophysical twin for apples. It was used to monitor temperature from different locations in the cold storage unit. This implementation was also performed to collect feedback for possible improvement in the application from users in an actual cold chain. Monitoring data is presented for two different time points during the storage, namely during the harvesting phase, where the cool room was opened and closed frequently, and new (warm) cargo was added (Figure 3.7 a), and later when the storage was entirely filled with apple and properly cooled down (Figure 3.7 b).

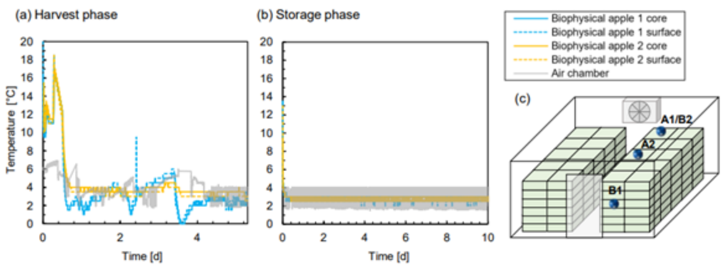

Figure 3.7. Temperature monitoring with biophysical apples in different spots in a cooling chamber. (a) Harvest phase with biophysical apple on crate top: near the evaporator (A1, blue) and near the room center (A2, yellow); (b) Storage phase with biophysical apple in the middle crate at the opposite end of the evaporator near the door (B1, blue) and in the top crate near the evaporator (B2, yellow). The temperature was monitored for ambient air (grey); (c) Schematic drawing set up including biophysical apple position for both of the monitoring experiments.

Figure 13: Temperature monitoring inside cold storages using the apple simulator

Academic study: "Development of biophysical food for monitoring postharvest supply chains for avocado and potato and deploying of biophysical apple" Lingxin You, Seraina Schudel, Thijs Defraeye https://doi.org/10.1016/j.jfoodeng.2022.111219

Academic Study 2: Using Machine Learning to generate an open-access cropland map from satellite images time series in the Indian Himalayan Region, Danya Li, Joaquin Gajardo, Michele Volpi, Thijs Defraeye https://doi.org/10.48550/arXiv.2203.14673

05. IMPACTS

- *Solar powered cold storages avoid GHG emissions associated with fossil fuel-based grid power and post harvest losses, thus contributing to climate mitigation. It also contributes to resilience of supply chains.*
- *Farmers who participated in the pilot saw a marked increase in their incomes. Further, it adds to their bargaining capacities and aids market linkages.*
- *The intervention also contributes to the Sustainable Development Goals. SDG 2 Zero Hunger, SDG 7 Affordable and Clean Energy, SDG 9 Industry, Innovation, and Infrastructure, and SDG 13 Climate Action are all addressed.*

5.1 ENVIRONMENTAL AND CLIMATE IMPACTS

By utilising solar energy and avoiding grid electricity and diesel consumption, the intervention avoids GHG emissions. Post harvest losses also represent emissions due to inefficiency and their decomposition into methane, which is mitigated. Further, the ability to store produce in times of supply chain shocks adds to farmers resilience.

Apart from the economic losses and the aspect of food security, post-harvest losses as discussed earlier also pose an environment problem, in the form of GHG emissions incurred in the production of lost produce. It also represents inefficient value chain and resource wastage. Mitigating these losses will not only result in reducing the monetary loss of income to farmers but also contribute to the other sustainability goals by increasing the availability of the micronutrient rich fruit, easing pressure on land and water resources, and reducing GHG emissions.

Table 4: IMPACT MATRIX

	Economic	Environmental	Social
SDG	SDG 9: Industry, Innovation & Infrastructure	SDG 7: Affordable and Clean Energy SDG 13: Climate Action	SDG 2: Zero Hunger
Local	Increased Farmer Incomes & Reduced stress Sales	Renewable Energy Generation	Better Bargaining Power & Improved Resilience
Regional / National	Improved Market Linkages and Conditions	Contribution to Climate and Sustainability Commitments	Penetration of Cold Chain and Improved Energy Access
Systemic	Improved Rural Infrastructure & Resilience to Supply Chain Shocks	Avoided GHG Emissions towards Climate Change Mitigation	Reduced Post Harvest Losses & Contribution to Food Security

Mitigation of GHG Emissions

Post-harvest losses add to emissions because of the additional food that is produced to meet the demand that could be met by the lost produce. But saving these losses avoids these emissions from the additional production. Further, without the cold chain, the produce would perish, and decompose into methane emissions. The carbon footprint of food produced and not consumed (i.e. either lost or wasted) is estimated to be 3.3 giga tonnes of carbon dioxide equivalent (GtCO2e) (CITE, ICAP).

Additionally, a typical cold storage unit runs for 16 to 18 hours per day on grid power. Diesel powered generators are also used across the country and are estimated to meet up to 10-15% of energy consumption for cold storage operations. Solarisation of cold storage and value-added services ensures more avoided GHG emissions as they do not rely on conventional fossil-fuel based sources of energy, and also reduces local pollution due to the use of diesel. These benefits are summarised in table xx.

Resilience

The cold storage further contributes to resilience to impacts of the climate change. While the COVID-19 lockdown brought to light and magnified previously unseen problems that already existed, the reality of climate

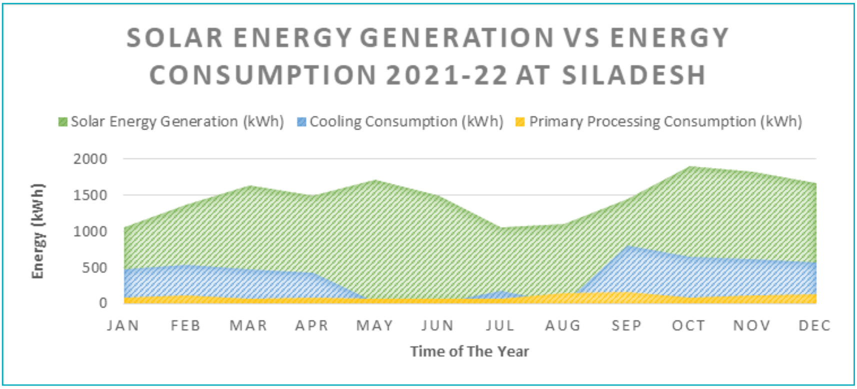

Figure 14: Solar energy generation vs total energy consumption for cooling and processing at Siladesh, Shimla, in 2021-22

Site	Siladesh	Andhra	Banjar	Sainj
SPECIFICATIONS				
Crops Stored	Apples	Apples, Plums, Apple Saplings	Apples, Plums, Persimmons, Tomato	Data NA
Capacity (MT)	20	10	10	8
ENERGY USE				
Average Annual Energy Consumption (kWh)	11880	4950	4950	2970
Average Annual Energy Generation (kWh)	23100	9240	9240	6930
Average Annual Surplus Energy from SPV (kWh)	11220	4290	4290	3960
ENVIRONMENTAL IMPACT				
CO_2 Emissions Avoided due to SPV ($kgCO_2$)	17325	6930	6930	5198
CO_2 Emissions avoided by diesel consumption for cooling and processing	2071	1059	1059	672
CO_2 Emissions avoided due to PHL avoided ($kgCO_2$)	6800	3200	2920	Data NA
Total Emissions Avoided	26196	11189	10909	5870
SOCIO-ECONOMIC IMPACT				
Average Annual Produce Stored (kg)	17000	8000	7300	Data NA
PHL Avoided (kg)	3400	1600	1460	Data NA
Annual Cost of Energy (Electrivity+Diesel) consumed cooling and processing (INR)	127440	65160	65160	41400
Potential Annual Revenue from Solar Net Metering (INR)	26400	8580	8580	7920
Potential Annual Revenue from Cooling Fee (INR)	102000	48000	43800	Data NA
Potential Revenue from REC (INR)	23100	9240	9240	6930
Net Potential Revenue from Carbon Credits (INR)	13100	5600	5450	2930
No. of Farmers / Growers Serviced	6	4	10	3
No. of Direct Jobs Created	2	1	1	Data NA
No. of Indirect Jobs Created	8	2	3	Data NA

Table 5: Impact and performance of the 4 installed cold storages on various parameters

change and unpredictable weather patterns have become the new normal in the mountain region ecosystems. Unseasonal rains also disrupt the last mile road and electricity networks for days at a stretch. This was starkly visible during the floods and landslides of 2023 in the State. Whole supply chains were disrupted, and the farmers could not produce harvested apples, which were already of lower volumes and quality due to adverse weather conditions. Thus, the need for building a resilient and distributed supply chain has become more necessary than ever before. Distributed cold chain and logistics infrastructure in this context contribute to resilience of supply chains and distribution networks in times of crises and shock. It allows the farmers to store their produce in times of disrupted supply chains.

5.2 Social and Economic Impacts

The pilot led to an overall increase of incomes for participating farmers in the three locations. The ability to sell their produce during favourable market conditions and with correct information on quality and shelf life empowers the farmers to negotiate better prices. The technology also partially mitigates the challenges due to geographic isolation.

Access to appropriate technologies enables small farmers and agri-entrepreneurs in Himachal Pradesh to increase the productivity, quality and market access of selected Horticulture commodities. It also allows them to overcome the geographic isolation leading to reduced access to energy, as well as reduce transportation related costs.

"The affordability and ease of access to technology empowers the farmers to have greater control over when, to whom, and at what prices to sell the produce. This translated into improved incomes."

Throughout the year, prices fluctuate substantially. While prices for apples tend to be low during harvest season in October, November, and

BOX 4: Potential for Apple farming in High Altitude Mountain Ecosystem in a Changing Climate

Erratic weather patterns is causing the apple cultivation to shift to higher altitudes to 1500–3500 above MSL (against 1200–1500 meters during 1980s), due to many factors including changes in chilling hours, total annual rainfall and mean surface temperature during the apple growing season. While the changing climate is reducing the apple production in low altitudinal regions of the state, it is creating new opportunities for apple cultivation in higher altitudes as conditions are getting more favourable for apple growth in those higher regions (Sahu, et al., 2020).

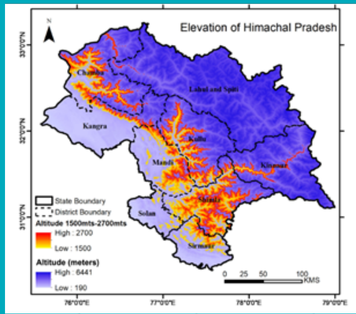

Figure 15: Map of regions with high elevation in Himachal Pradesh

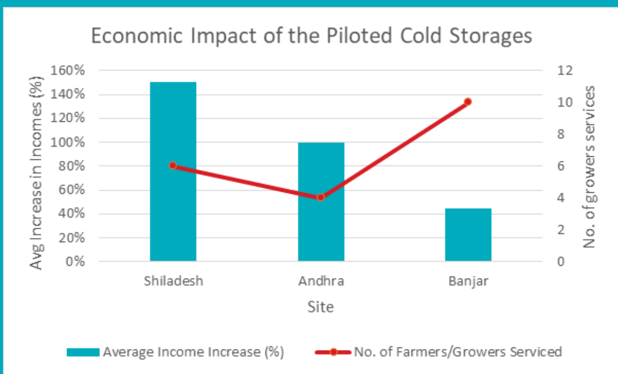

Figure 16: Economic impact of the piloted cold storages

December due to a sudden glut in supply, they tend to rise during February to April. Another major issue for small-scale farmers is that large-scale farmers and private cold storages decide the market price as they provide most of the stored apples and can therefore decide when to open the cold store. The small farmers are thus forced to sell at the same period at worse conditions.

The affordability and ease of access to technology empowers the farmers to have greater control over when, to whom, and at what prices to sell the produce. This translated into improved incomes.

The cold storage allows the farmers to avoid selling at low prices during the peak season, and YVCCA informs farmers about the best time to sell in the off season based on market prices as well as the quality of their produce. Once the intervention is scaled up into distributed clusters, it will attract buyers at the farmgate. Rather than distress sale depending upon decisions made by large farmers and cold store owners, the farmers can decide to sell the produce to buyers offering them the best and the highest price.

Additionally, in horticulture, women continue to provide significant labour and supervisory input to pre-harvest and post-harvest activities. This intervention has potentially significant impact on promoting gender inclusiveness through employment creation in post-harvest management and processing which is likely to generate employment for rural women.

Economically, the intervention promotes efficiency in the value chain preventing losses, as well as increases farmer as shown in figure 16. ■

06. IMPLEMENTATION STRATEGY

Successful implementation of the project was facilitated by successful partnerships between the end users, local government bodies, the technology provider, and other backend technical and professional services. This approach is informed by the recognition that systemic and muti-dimensional challenges cannot be addressed by any single actor alone. It requires collective and coordinated action to achieve positive social impact and deliver goods and services more efficiently and effectively. Consequently, the implementation strategy envisaged collaboration with:

- Local government bodies for easing regulatory approvals, access to data, and facilitation of project implementation.
- Private tech-businesses for efficient service delivery
- Farmer producer organisations for taking ownership of the cold storages and managing them and the end users efficiently.
- Development organisations for facilitation between farmer groups, government bodies, and private sector
- Technical and professional partners for ease of installation, maintenance, and operation
- Capacity development organisations to upskill the farmers and farmer collectives. ■

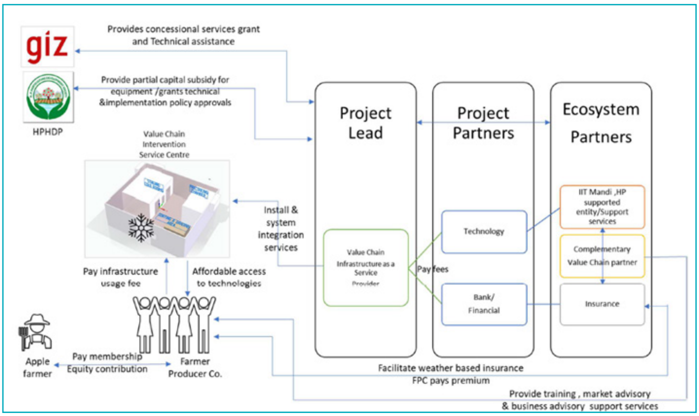

Figure 17: Service Delivery Model (CoolCrop, 2020)

07. THE ROAD AHEAD

- *Catering to increasing demand for cold chain needs effective partnerships between the private tech-businesses and government to deliver solutions efficiently.*
- *Multi-stakeholder partnerships to create an environment for conducive policies, their implementation, and unlocking of public and private finance is needed at macro level across agriculture, technology, and finance sectors. This will also resolve current and future challenges.*
- *At the ground level, development organisations can facilitate the implementation process between farmers and stakeholders.*

The need to manage post-harvest losses presents an opportunity for upscaling of customised technology. Additionally, the need for cold chain in India's horticulture sector is a pressing one, with various government schemes pushing for the same. Keeping this in mind, the potential need for solar powered cold storage is only going to increase.

Catering to such an increasing demand by Government programmes alone is improbable. Effective partnerships between the private tech-businesses and government can deliver more efficiently.

Challenges faced during the course of implementation needs more attention by different stakeholders at various levels. The intervention on solar powered cold storages sits at the intersection of agriculture, supply chains and transportation, energy, and finance. Stakeholders i.e. both public and private players from all sectors have a role to play in the scaling of such customised and need based intervention, apart from farmers and tech-businesses themselves. Collaboration among various stakeholders is crucial, including farmer cooperatives, government agencies, financial institutions, and private sector partners. Important stakeholders and their

Table 4: STAKEHOLDER MATRIX

	Agriculture & Supply Chains	Energy & Technology	Finance
Government / Public Sector	MoA&FW and its Nodal and State Departments	Ministry of New and Renewable Energy & Power Distribution Companies (DISCOMS)	Public banking, finance, and insurance institutions and companies
	Role: Facilitating a conducive policy environment, schemes, and their implementation. This can also make unlocking both public and private finance easier.		
Private Sector	Farmers, Collectives, FPOs/FPCs Buyers and traders Transporters and distributors Role: Cooperative and efficient use and management of the service.	Technology manufacturers Role: Quality service delivery and technical grievance redressal.	Private banking, finance, and insurance institutions and companies Role: Provide financial backing and/or capital investment.
	Agri-tech businesses and social enterprises such as CoolCrop Technologies, S4S Technologies, etc. Role: Ground level needs assessments, technology development and innovation, entrepreneurial approach to problem solving, ensuring quality service to end users, and facilitation of the process.		
Civil Society	Non-government organisations and civil society organisations such as SELCO Foundation, APMAS, etc. Role: Primarily a facilitative role at teh ground level during project implementation, between farmers, local government bodies, and tech-businesses.		

roles are enumerated in Table 6.

Some specific challenges relate to participation of power distribution companies to operationalise net-metering, capacity building of farmers, financing of the capital investments, and restrictions on land ownership due to State regulations.

While a certain degree of finance has been unlocked, more finance can be unlocked via banks, the Agriculture Infrastructure Fund of the Department of Agriculture & Farmers Welfare, and other such mechanisms.

Further additional streams of revenue can come from tapping into the voluntary carbon market. The quantum of carbon credits generated from both avoided emissions due to solar technology, avoided consumption of diesel, and from avoided PHL, especially after the intervention is scaled up, can be significant revenue streams. In fact, we hope that tapping into such carbon finance can even support the scaling up of this intervention, bearing a part of upfront investment costs.

In future, some competition for the on-farm solar cold storage may come from other cold storage facilities located in the same region. Advancements in transportation and preservation technology could pose a potential future threat to the local cold storage, as they may provide alternative options for storing and transporting apples.

In conclusion, the solar powered cold storage intervention has significant potential for scaling up and replication, but it requires additional resources, stakeholder involvement, and a blended finance business model for sustainable and inclusive economic growth. The major recommendations are as follows:

Business Model: A CaaS model would require a viable and sustainable business model, which includes the pricing strategy, payment terms, and service level agreements with the smallholder farmers. The pricing strategy should be attractive enough to encourage farmers to use the facility, while also covering operational costs. This needs to be be drawn up urgently and take into account different scenarios of geographical utilization.

Funding: The initial funding required for setting up the cold storage facility would be significant. Funding could come from a combination of sources, such as government subsidies, private investments, or microfinance institutions.

Maintenance and Repair: Regular maintenance and repair of the cold storage facility are critical to ensure its longevity and efficient operation. A maintenance plan should be developed and costs calculated for different scenarios of geographical coverage.

Partnerships: Partnerships with other organizations or stakeholders can help to reduce the costs of setting up and operating the facility. This could include partnerships with energy providers, logistics companies, and farmer cooperatives.

Training and capacity building: Education and outreach programs must be developed to ensure effective utilization and establish strong business models with forward market linkages. While the cooperative/ FPC approach promotes collective ownership and decision-making by the FPCs, it can lead to conflicts or disagreements among members. Consequently there is a high need for capacity building as strong management and technical expertise are required.

Production and Crop Mix: An assessment of crop mix and crop calendar should be conducted to analyze crop-wise production by cluster and determine which other products can be stored to ensure full capacity utilization and capitalization.■

References

1. AEEE. (2022). Cold Chain Energy Efficiency in India: Analysis of Energy Efficiency Opportunities in Packhouses. World Bank. Retrieved from https://aeee.in/wp-content/uploads/2022/03/WB-BEE-AEEE-cold-chain-energy-efficiency-in-india.pdf

2. BASE & EMPA. (n.d.). Retrieved from Your Virtual Cold Chain Assistant: https://yourvcca.org/

3. Bhatt, S. (2016, January 15). Powering Cold Storage Plants. Retrieved from Cooling India: https://www.coolingindia.in/powering-cold-storage-plants/#:~:text=The%20present%20cold%20storage%20capacity,of%20the%20installed%20electrical%20capacity.

4. CoolCrop. (2020). Himachal Pradesh Apple Value Chain Intervention Project. CoolCrop Technologies Private Limited.

5. DoA&FW. (2023, June 28). Area and Production of Horticulture crops for 2021-22 (Final). Retrieved from Department of Agriculture and Farmers Welfare: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fagricoop.gov.in%2Fsites%2Fdefault%2Ffiles%2F2021-22%2520_Final.xlsx&wdOrigin=BROWSELINK

6. Evangelista, R. (2022). Final results from CoolCrop apple survey. Coolcrop Technologies & BASE.

7. HPHDS. (2023). Project Context. Retrieved from Himachal Pradesh Horticulture Development Society: https://hds.hp.gov.in/GeneralpageWithTemplate.aspx?key=PROJKEY0001

8. Jha, S., Vishwakarma, R., Ahmad, T. R., & Dixit, A. (2016). Report on Assessment of Quantitative Harvest and Post-Harvest Losses of Major Crops/Commodities in India. Ludhiana: ICAR-CIPHET. Retrieved from https://www.researchgate.net/publication/289637983_Assessment_of_Quantitative_Harvest_and_Post-Harvest_Losses_of_Major_CropsCommodities_in_India

9. MoA&FW. (2019). Agriculture Census 2015-16 (Phase I): All India Report on Number and Area of Operational Holdings. Agriculture Census Division, Ministry & Agriculture and Farmers Welfare, Government of India. Retrieved from https://agcensus.nic.in/document/agcen1516/T1_ac_2015_16.pdf

10. MoEFCC. (2019). India Cooling Action Plan. Ozone Cell. New Delhi: Ministry of Environment, Forest & Climate Change. Retrieved from http://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-

version080319.pdf

11. MoEFCC. (2021). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.

12. Sahu, N., Saini, A., Behera, S., Sayama, T., Sahu, L., VTC, N., & Takara, K. (2020, July 10). Why apple orchards are shifting to the higher altitudes of the Himalayas? Plos One. doi:https://doi.org/10.1371/journal.pone.0235041

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Gmbh

Registered offices
Bonn and Eschborn, Germany

Green Innovation Centres for the Agriculture and Food Sector - India
No. 38/43, First Floor, 10 A Main Road, Fifth Cross
Block 1, Jayanagar
Bengaluru – 560 011, India
T (India) +91 80 46664000 (Extn. 6000)

E greeninnovationcentreindia@giz.de
I www.giz.de/en