



कृषि एवं किसान
कल्याण मंत्रालय
MINISTRY OF
AGRICULTURE AND
FARMERS WELFARE
सत्यमेव जयते

NCCD
National Centre for Cold-chain Development

ENERGY TRANSITION IN COLD CHAIN INFRASTRUCTURE

NCCD
National Centre for Cold-chain Development



Acknowledgement

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Acknowledgments

September 2025

NCCD is grateful to all experts and specialists for providing insights during the preparation of this report. We would like to thank Shakti Sustainable Energy Foundation for supporting the study and PwC India, the knowledge partner for the study.

The team extends its sincere gratitude to:

- **Mr. Devesh Chaturvedi, Secretary, Ministry of Agriculture and Farmer's Welfare**
- **Mr. Priya Ranjan, Joint Secretary, Ministry of Agriculture and Farmer's Welfare**

The team also acknowledges the support provided by the various organizations and experts during the stakeholder consultation. We are thankful to the Ministry of Agriculture and Farmers Welfare, other line ministries, industry associations, academia, technology providers, consultants, and other experts for providing their input during the development of this report.

This study is developed as part of the NCCD's ongoing efforts and initiatives towards streamlining, standardizing the cold chain sector in India with an aim and vision of ensuring that the cold chain sector remains both efficient and sustainable.

Message from the Secretary, MoAFW

The Ministry of Agriculture and Farmers' Welfare is committed to enhancing farmers' livelihoods and advancing the holistic growth of Indian agriculture. Our vision is a sustainable, competitive, and inclusive agricultural sector that ensures national food and nutritional security while supporting the value addition to the farmer's produce through various initiatives. We pursue this mission by strengthening infrastructure, accelerating technology adoption, and fostering value addition across agri-food value chains.

Farmers continue to face persistent challenges of significant post-harvest losses, limited access to efficient and reliable cold chain infrastructure, and value loss of their produce which directly impact their income, and which also undermines our collective food security. Addressing these challenges is central to reducing waste, lowering energy costs and building resilience across value chains.

It is in this context that I am delighted to present the report, Energy Transition in the Cold Chain Sector in India, a timely and strategic contribution to our ongoing efforts towards farmers welfare and overall development of the agricultural value chains to meet the current needs of modernization and decarbonization. This report offers a strategic roadmap to strengthen cold chain infrastructure through innovative, energy-efficient practices, with actionable insights, guiding stakeholders toward a resilient agricultural value chain and thereby supporting food security, and economic prosperity.

Together, let us work towards a future where India's agricultural potential is fully realized, benefitting the stakeholders.

This study is the outcome of extensive collaboration across government and state departments, industry associations, industry, academia, financial institutions, and other stakeholders. I extend my sincere appreciation to all contributors for their dedication to this important effort.

I am confident that this energy transition roadmap will pave the way for a more sustainable and efficient cold chain ecosystem. Let us move forward together in building a robust, energy-efficient agricultural infrastructure that empowers our farmers and secures India's food future.



Shri Devesh Chaturvedi

Secretary,
Ministry of Agriculture & Farmers' Welfare

Message from the Joint Secretary, MoAFW

A robust and modern cold chain is vital to reducing post-harvest losses, ensuring the delivery of safe and high-quality food, while also supporting our farmers. In today's context, transitioning the agricultural cold chain toward energy-efficient technologies, renewable energy integration, and digital solutions is not only necessary, but it also presents a significant opportunity. Such advancements can lower operational costs, reduce emissions, and enable longer, more reliable storage and distribution of perishables.

It is with great pleasure that I present the study report “Energy Transition in the Cold Chain Sector in India”, a timely assessment by National Centre for Cold Chain Development (NCCD).

This report lays a strong foundation for collaborative action among stakeholders, including cross-ministerial engagement, to build energy-efficient cold chain infrastructure that adds greater value to farmers' produce. It offers strategic direction to strengthen the sector and support India's broader goals of sustainability and agricultural resilience.

I extend my sincere appreciation to all contributors—government departments and agencies, industry leaders, research institutions, academia, individual experts, OEMs, and other partners—whose insights and field experience have enriched this study. I also commend NCCD for their leadership and commitment in steering the development of this important report.

Together, let us work toward a future-ready cold chain ecosystem that empowers our farmers and supports India's food and energy security.



Shri Priya Ranjan

Joint Secretary Horticulture,
Ministry of Agriculture & Farmers' Welfare

Foreword by the COO - NCCD

As the national platform for cold-chain development, the National Centre for Cold-chain Development (NCCD) advances India's cold-chain ecosystem by setting and updating technical standards, supporting applied research and skill development, and advising on integrated, end-to-end infrastructure. By strengthening standards and practice across storage and transport, NCCD helps reduce post-harvest losses, improve market access for farmers, and enhance the year-round availability of fresh produce at affordable prices.

This report on Energy Transition in the Cold Chain Sector in India, aligns closely with NCCD's mandate by offering a strategic roadmap to modernize cold chain systems through energy-efficient technologies and sustainable

practices—strengthening the sector's resilience and supporting long-term agricultural value creation.

As part of NCCD's broader program, this report further advances its mission by operationalizing the Engineering Guidelines and Minimum System Standards 2025 into practical pathways for upgrading legacy assets and guiding new builds and identifying high impact efficiency and renewable energy interventions across storage and transport. It also highlights the role of digitization, certification, and capacity building to improve performance and safety. Together, these actions strengthen infrastructure reliability and affordability for producers and consumers while aligning the sector with India's sustainability goals.

Developed through extensive engagement across multiple stakeholders, it draws on consultations, field surveys, and site assessments with state departments, industry, logistics operators, OEMs, utilities, financiers, and producer organizations to reflect India's diverse infrastructure and practical operating realities.

I extend my sincere thanks to the entire team and the stakeholder whose contribution made this study possible. I am confident that this roadmap will help catalyze a more sustainable, efficient, and resilient cold chain, advancing food security, farmer prosperity, and climate stewardship.



Shri Asheesh Fotedar

COO,
National Centre for Cold-chain Development

Message from Shakti Sustainable Energy Foundation

It gives me great pleasure to congratulate the entire team on the launch of the report “Energy Transition in Cold Chain Infrastructure”. We would like to thank the Ministry of Agriculture and Farmers’ Welfare (MoAFW) for their leadership and the National Centre for Cold-chain Development (NCCD) for their guidance and support in shaping this work. This milestone reflects deep commitment, close collaboration, and tireless work by all partners. It also underscores the central role that a modern, reliable, and efficient agricultural cold chain plays in improving the produce value realization to the farmers, reducing post-harvest losses, enhancing food and advancing India’s climate and clean energy goals.

The study takes a clear, rigorous approach: it focuses on three key perishables, identifies leading producer states, and maps the energy transition potential across each value chain—state by state and then at the national level. In doing so, it moves beyond abstract targets to provide a practical, evidence-based pathway for change based on local realities, informed by stakeholder consultations and field visits.

The report offers a pragmatic roadmap for 2025–2031, detailing how to retrofit existing facilities with higher-efficiency technologies, improve operations and maintenance, and integrate clean energy—particularly solar—to cut costs and reduce dependence on grid power and diesel. It also quantifies the potential for energy savings and greenhouse gas reductions as a result of this transition.

My sincere appreciation for all the efforts to the individuals and teams involved in the research to release this report. Together, we can help build a sustained, future-ready cold chain ecosystem for India—one that benefits farmers and consumers alike while advancing an orderly energy transition.



Ms. Vatsala Joseph

Interim Chief Executive Officer
Shakti Sustainable Energy Foundation

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Executive Summary

Introduction

India stands proudly as the world's second-largest producer of fruits and vegetables. The country has witnessed remarkable growth in agricultural production over the past decade. This growth has been accompanied by substantial advancements in post-harvest infrastructure, reflecting the nation's commitment to enhancing food security and agricultural efficiency. Despite these achievements, the challenge of ensuring that all citizens have access to sufficient and nutritious food persists. Significant post-harvest losses still occur, particularly in fruits and vegetables, where between 5% to 15% (MoFPI, Post Harvest Food Loss, 2022) of the harvest is lost along the supply chain.

Addressing these inefficiencies is crucial to achieve two primary goals: improving food security through reduced wastage and increasing farmers' incomes by optimising supply chain systems to enhance market access and price realisation. An integrated and reliable cold chain system is pivotal to achieve these goals, as it plays an essential role in maintaining the quality and nutritional value of perishable goods from farm to fork. By delivering

optimal temperature management throughout the harvesting, storage and distribution processes, the cold chain minimises post-harvest losses and maximises the reach of fresh produce across the nation. While noteworthy strides have been made in expanding cold chain infrastructure, there is still room for enhancing its integration and efficiency.

This report aims to address these challenges by conducting a comprehensive evaluation of the current cold chain landscape in India. It aims to identify infrastructure challenges and evaluate the potential for energy transition by developing a roadmap that encourages the use of energy-efficient and renewable technologies. By analysing three key perishables and their movement across supply chains, the study endeavours to create actionable strategies that enhance efficiency and support sustainable growth. Through these objectives, the report offers strategic insights and recommendations vital for maximising the cold chain's full potential in supporting India's overarching food security and economic development goals.

Indian cold chain sector landscape

The Government of India recognises the cold chain sector as a 'sunrise industry' and has taken proactive measures to foster its growth. While initial development was largely driven by increasing demand for perishable goods, government policies have played a crucial role in accelerating its expansion. Early initiatives primarily focused on establishing cold storage facilities near harvesting sites. However, recent years there have been a shift towards a more integrated approach. The government now explicitly recognises the need for an integrated

cold chain ecosystem, which encompasses not only storage but also transportation, distribution and technological integration across the entire value chain. This shift in focus signifies a deeper understanding of the complexities involved and a commitment to developing a comprehensive and efficient cold chain network across India. The policy push is driving the growth of Cold Chain Infrastructure (CCI) in India and India's cold chain infrastructure is on the cusp of significant growth, driven by a confluence of factors like:

- Rising demand from the middle class
- Expansion of retail and e-commerce
- Technological advances

The cold chain sector in India primarily consists of packhouses, cold storages (including cold rooms, controlled atmosphere storages and chillers), refrigerated transport (reefer) vehicles and ripening chambers. Most of the CCI currently established in India caters to agricultural and horticultural produce. According to the Ministry of Food Processing Industries (MoFPI), as of 2017, approximately 75% of the cold storage infrastructure in India catered solely to the storage of potatoes only.

India's current cold chain infrastructure landscape primarily consists of standalone cold storage facilities, with significantly fewer packhouses, ripening chambers and reefers, indicating a substantial opportunity to address the existing gap, with this sector poised to grow rapidly. By 2031, India is likely to have 2.52 lakh metric tonne (LMT) of packhouse capacity, 436.5 LMT of cold storage capacity, 2.65 LMT of ripening chamber capacity and more than 33,000 reefer vehicles. These numbers are based on the growth projections anticipated from the previous growth rates. However, the National Centre for Cold-chain Development (NCCD), a think tank setup under the Ministry of Agriculture and Farmers' Welfare (MoAFW), is conducting a study to determine the exact capacity of the cold chain infrastructure in the country.



Regional landscape of the cold chain infrastructure

The nature of cold chain infrastructure varies across regions, that reflects the diverse agricultural outputs and priorities of different states. Notably, the number of packhouses remains relatively low compared to cold storage facilities. Fewer than 250 integrated packhouses existed as of 2015. Maharashtra leads in this aspect of infrastructure and accounts for approximately 70% of the nation's packhouse facilities.

Cold storage constitutes the most extensive cold chain infrastructure. Uttar Pradesh has the highest concentration due to its substantial agricultural yield, making it the largest state in terms of agriculture and horticulture output (MoAFW, Horticulture Statistics at a Glance, 2021). As of May 2024, India has 8,698 cold storage facilities of various types. These facilities provide a total capacity of 395 lakh metric tonne (NCCD, Cold Storage Infrastructure as of May 2024, 2024). States like West Bengal and Gujarat also play key roles, underscoring the significant reach and importance of cold storage capacity across the nation.

Ripening chambers, crucial for climacteric fruits like bananas and mangoes. Their number has gradually increased, reaching 812 in 2015. Andhra, Maharashtra, and Karnataka dominate this segment. These states are major banana-producing regions. This targeted growth reflects that authorities have made concerted efforts to enhance ripening infrastructure where it is most needed.

Refrigerated transport remains underutilised, as highlighted by NCCD in their 2015 gap assessment report. Refrigerated transport is essential for maintaining the cold chain. As of 2015, approximately 9,000 reefer vehicles were in operation, primarily observed near urban and semi-urban regions, with an 85% infrastructure gap (NCCD, All India Cold-chain Infrastructure Capacity (Assessment of Status & Gap), 2015). These vehicles predominantly serve export-oriented perishables and industries that require stringent temperature controls, such as dairy and processed foods. Refrigerated transport thus plays an integral role in India's cold supply chain.

Policy development and government support to develop the cold chain sector

The Central Government, spearheaded by the Ministry of Agriculture and Farmers' Welfare and the Ministry of Food Processing Industries, plays a crucial role in creating a comprehensive policy framework for the sustainable growth and modernisation of India's cold chain sector. Their policies are aimed at enhancing food security, mitigating post-harvest losses and aligning with national goals for environmental stewardship and economic growth. Key initiatives by agencies such as the National Horticulture Board (NHB) and the Mission for Integrated Development of Horticulture (MIDH) are pivotal in promoting infrastructure that incorporates energy-efficient and renewable technologies. NCCD further underscores these efforts through recent updates to engineering guidelines, integrating technological advancements to meet evolving market demands and boost the adoption of renewable energy and energy efficiency across the sector.

State governments also play a vital role by implementing localised initiatives that address

specific agricultural needs and regional priorities. By facilitating statutory approvals, providing land and promoting state-specific schemes, they complement national strategies and enhance cold chain capabilities at the regional level. These collaborative efforts between the central and state governments are crucial for developing a robust and efficient cold chain network, which empowers farmers, improves market access and supports sustainable agricultural practices across the country. Some examples of key state policies include the UP-Food Processing Policy, UP Warehousing and Logistics Policy, Maharashtra Agricultural Export Policy, Maharashtra Agribusiness Network (MAGNET) policy, Andhra Pradesh Food Processing Policy, among others.

In addition to the policy initiatives, the government also supports the cold chain sector through a diverse array of financing mechanisms, including subsidies, loans and tax incentives, that aim to propel the sector toward sustainability and economic viability.

Global perspective on practices in the cold chain sector

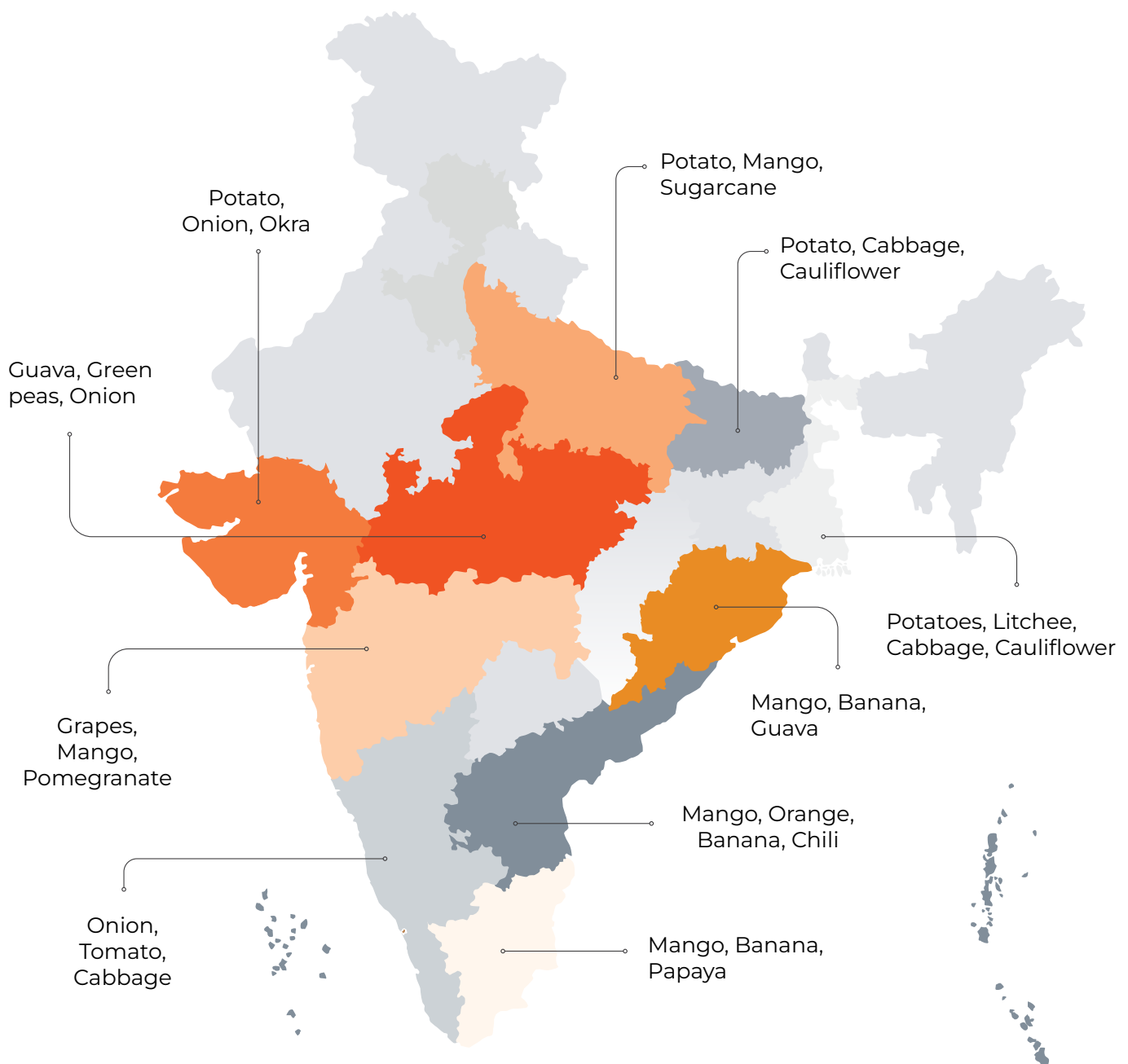
The global cold chain sector is undergoing a transformative shift driven by sustainability, technological innovation and resilience imperatives, with significant relevance to India's energy transition strategies. The adoption of renewable energy, such as solar-powered cold storages, and energy-efficient refrigeration technologies using low-GWP refrigerants like ammonia (R717), CO₂ (R744), and hydrocarbons (R290) is reducing carbon footprints. Regulatory frameworks like the EU's F-Gas Regulation and the US AIM Act are accelerating the phase-out of high-GWP HFCs, promoting natural and HFO refrigerants, a trend India emulates through the HPMP to meet its Kigali Amendment commitments. Additionally, circular economy practices, such as reusable packaging and refrigerant recycling, minimise waste, offering a model for India to enhance sustainability in its cold chain, critical for reducing post-harvest losses (up to 15%) and supporting food security.

Technological advancements and resilience strategies further strengthen global cold chain integration, offering actionable insights for India. Internet of Things (IoT), artificial intelligence and blockchain technologies enable real-time monitoring, traceability and supply chain optimisation, addressing India's fragmented cold chain challenges. Automation and built-to-suit facilities near production hubs enhance efficiency, while strategic partnerships and mergers improve supply chain resilience against geopolitical and climate disruptions. These trends support India's need for modernised infrastructure, such as solar-powered micro cold storages and packhouses, to create a seamless cold chain. By adopting these global best practices, India can achieve a sustainable, integrated cold chain.

National landscape of horticulture perishables and the selection of perishables for assessment

India's horticultural landscape is anchored by the production of key perishables such as potatoes, onions, bananas, sugarcane, grapes, mangoes, chillies, among others, each with specific temperature and humidity requirements critical for optimal storage and distribution. These commodities are produced largely across major states like Andhra Pradesh, Gujarat, Maharashtra, Uttar Pradesh and West Bengal, which collectively account for a significant portion of India's horticultural output. Uttar Pradesh leads with a production share of approximately 13%, followed

closely by Madhya Pradesh and West Bengal, each contributing around 10%. The study focused on three key perishables—potatoes, grapes and chillies—for an in-depth evaluation of cold chain infrastructure across specific states. The selection process considered seven national-level criteria, which are production volume, production value, value per tonne, wastage percentage from production, potential future demand, export value and shelf life of perishables. It also included two key state-level factors: responsiveness of state authorities and stakeholder availability.



Potato cold supply chain analysis

Potatoes play a crucial role in India's agricultural sector as a staple food and a low-value crop, with 56.1 million metric tonnes produced and a production value of INR 513 billion in 2021 (MoAFW, Horticulture Statistics at a Glance, 2021). Predominantly grown in states like Bihar, Gujarat, Madhya Pradesh, Punjab, Uttar Pradesh and West Bengal. These states account for approximately 89% of the nation's output. Potatoes dominate India's cold chain infrastructure, occupying over 75% of cold storage capacity. This primarily involves older, single-commodity facilities, presenting an opportunity to enhance energy efficiency.

The cold chain infrastructure across Uttar Pradesh shows medium to high utilisation but mostly uses old technologies, particularly in facilities that are more than 20 years old (~70%). These facilities were observed to be operating on a few business models. The primary business model observed was the rental model, involving either the farmers or the traders using the cold storages to store the commodity on a rental basis. This model is prevalent across most of the potato cold storage facilities in the country. In terms of financing, more than 95% of India's cold chain infrastructure is privately owned, either through proprietorship or cooperatives, and the same was observed for the potato storages as well.

Table: ES1 Summary of potato cold chain infrastructure

Assessment parameter	Uttar Pradesh	West Bengal	Gujarat
Average utilisation (2024)	90-100%	60-70%	70-80%
Relative age of facilities	Old – Mid Average age: 20-25 years	Old Average age: 30+ years	Mid Average age: 15-20 years
Business models	Rental, trader-rental	Trader-rental	Rental, trader-rental
Financing mechanisms	Private, cooperative	Private, cooperative	Private, cooperative
Exports landscape	Low	Low	Mid
Existing technology landscape	Old – Semi modern	Old	Semi modern – modern

Grapes cold supply chain analysis

Grapes are integral to India's perishable landscape, with the country ranking as the fifth-largest global exporter. In 2021, India produced 3.35 million metric tonnes (MoAFW, Horticulture Statistics at a Glance, 2021), with Maharashtra alone contributing around 70% of this yield and accounting for over 80% of grape exports. Nashik, supported by Pune and Sangli, is a major production hub within the state. Together with Karnataka, these areas represent 95% of India's grape production.

Grapes are largely consumed directly, with a portion processed into juice and raisins. Post-harvest, grapes are pre-cooled and stored in Type 2 multi-commodity cold storage facilities, which are essential for maintaining quality in distribution and exports.

Grape cold chain infrastructure features multi-commodity storages, integrated packhouses, food processing units and reefer transport, with utilisation rates between 70% and 90% in 2024, based on site visits and interactions with the Maharashtra Cold Storage Association (MCSA). Facilities are mid-aged, typically 15 to 20 years old, and leverage diverse business models like rental, trader-rental, distributor rental, B2B and food processing combined with storage. Financing primarily comes from private sources, cooperatives and Farmer Producer Organisations (FPOs). India boasts a strong export landscape for grapes, supported by a semi-modern to modern technology infrastructure that enhances efficiency and international market reach.

Chilli cold supply chain analysis

Chilli holds significant economic value within India's agricultural landscape, with Andhra Pradesh leading production. The state contributes nearly 32% (Pradesh, n.d.) of the national output, cultivating over 15 varieties like the export-favoured 'Theja'. Karnataka, Madhya Pradesh and Telangana are also key producers. A dynamic value chain supports chilli's market presence, where price fluctuations dictate fresh sales or processing into chilli powder for extended shelf life. Cold chain infrastructure, enhanced by FPOs utilising farmgate cold rooms, is vital for maintaining quality, reducing post-harvest losses, and stabilising farmer incomes amid market variability. The infrastructure for chilli cold chains includes bulk cold storages, integrated packhouses,

solar cold rooms, FPO collection centres, solar dryers and ripening units, achieving an average utilisation of 70% to 80% in 2024, as highlighted by the horticulture department in Andhra Pradesh. The facilities, with an average age of 10 to 15 years, reflect a mix of mid to new developments. They operate under various business models such as rental, trader-rental and food processing combined with storage. Financing is primarily supported by private investments, cooperatives and FPOs. India maintains a moderate exports landscape, and the existing technology is described as semi-modern to modern, with enhanced operational efficiency and market competitiveness.

Key findings from perishables assessment for the development of the energy transition roadmap

The cold chain sector in India functions through a multitiered supply chain that is critical for maintaining the quality of perishable goods from farm to consumer. At the farmgate level, infrastructure remains limited, with most facilities being standalone cold storage or small PV-powered solar cold rooms concentrated at FPOs in states like Andhra Pradesh and Maharashtra. Despite government efforts through schemes like MIDH and NHB, renewable energy adoption remains gradual.

The mid or hub level, located near urban and semi-urban centres, features more developed infrastructure with stable electricity. This leads many farmers to prefer these facilities. Bulk cold storage, predominantly using ammonia-based

systems subsidised by NHB/NHM, is prevalent here. This presents significant opportunities for energy transition via efficient technologies and renewable energy solutions.

The distribution level relies primarily on mobile infrastructure such as refrigerated and non-refrigerated vehicles. These vehicles predominantly transport exports and high-demand fruits due to cost and technology constraints. Government initiatives aim to promote refrigerated electric vehicles, despite their higher costs compared to traditional vehicles. Across all levels, significant potential exists for energy conservation through advanced technology adoption and enhanced infrastructure.

Technology landscape Static infrastructure

The cold chain facilities primarily employ Vapour Compression Mechanism (VCM), which uses ammonia as the main refrigerant for cold storages (bulk and hub), with R-404A, R-134a among others, being used in packhouses and ripening chambers. Insulation practices reveal a shift from older, less efficient materials like thermocol and rice husk to modern Polyurethane Foam (PUF) in newer

facilities, underscoring improvements in energy efficiency. To enhance sustainability, the sector focus on adopting efficient refrigeration systems, greener refrigerants (specifically for packhouses, and ripening chambers) and uniformly applying advanced insulation across facilities to optimise efficiency and minimise environmental impact.

Table ES2: Refrigeration system, refrigerant and insulation used in static cold chain infrastructures

	Packhouse (Integrated)	Bulk cold storage (Type 1/4)	Hub cold storage (Type 2)	Ripening chamber (Type 3)
Refrigeration system	Vapor Compression Mechanism (VCM)	VCM with ammonia bunker system VCM with unitary fan system		VCM and artificial ethylene generation system
Refrigerant	Predominantly R-404A	Ammonia (R717)	Ammonia (R717) R-404A	R-134a R-404A Ammonia (R717) if the ripening chambers are integrated with Type 1 cold storages
Insulation	PUF	Old facilities (>10 years) – thermocol, rice husk, glass wool New facilities (<10 years) - PUF		PUF

Mobile infrastructure

The assessment of India's refrigerated transport sector reveals a need for more sustainable practices. Transitioning to environmentally friendly refrigerants is crucial to meet regulatory guidelines and secure subsidies. While technology such as PUF insulation is present, however disparities exist between corporate fleets and small operators in terms of maintenance

and digitisation practices. Enhancing digital tool adoption among smaller operators and establishing consistent maintenance standards are vital steps. Overall, focusing on sustainable refrigerants, improved maintenance and broader technological integration will enhance efficiency and sustainability across the cold chain system.

Business model and financing landscape

The cold chain sector in India utilises a variety of business models and financing mechanisms to support both static and mobile infrastructure.

- **Static** infrastructure, such as cold storage and processing facilities, operates on business models including rental, trader rental, distributor rental, B2B and processing models. These models cater to diverse operational needs, facilitating storage, logistics, and value-added activities to drive economic growth. Financing often relies on capital expenditure from private ownership and cooperatives. The FPO model has gained traction in states like Maharashtra and Andhra. Government-

owned facilities, though limited, play a crucial role in ensuring food security.

- **Mobile** infrastructure, essential for refrigerated transport, leverages business models like third-party logistics (3PL), asset-heavy fleet ownership, cold chain service leasing and last-mile delivery solutions, driven by the rise of e-commerce. These models enhance logistics efficiency and provide strategic control over supply chains. Financing primarily involves bank loans and is supplemented by leasing options to offer flexibility and preserve cash flow.



Energy consumption in the cold chain sector

The study team estimated the energy consumption for India's cold chain infrastructure (CCI) using 2015 as the reference year. The study team also relied upon several published reports to assess the growth of CCI. Further, the study team used site visit assessments to over 80 CCI facilities across the targeted states for the selected perishables. The cold chain infrastructure's energy consumption patterns underscore the need for strategic improvements, particularly in older facilities.

- Packhouses contribute minimally to overall energy use, accounting for less than 1% of overall consumption.
- According to the analysis, old bulk cold storage facilities (over 20 years old) that constitute about 70% of the bulk cold storage category consume the most energy. They account for 1,643.26 GWh or 33% of the overall consumption.

- Similarly, hub cold storage facilities show a trend of diminishing consumption with newer setups. This indicates the benefits of modern systems.
- Reefer vehicles stand out as major energy consumers and comprise of 21% of overall consumption. This trend highlights the potential for transitioning to electric or hybrid models to enhance cooling efficiency in mobile infrastructure.

The key focus for energy transition should be upgrading older cold storage, majorly the Type 1 facilities, and reefer vehicles with energy-efficient technologies. These efforts can significantly reduce energy usage, optimise operational efficiency, and align the sector with broader sustainability goals. This approach ensures a more environmentally conscious cold chain operation.

Energy transition: challenges and opportunities

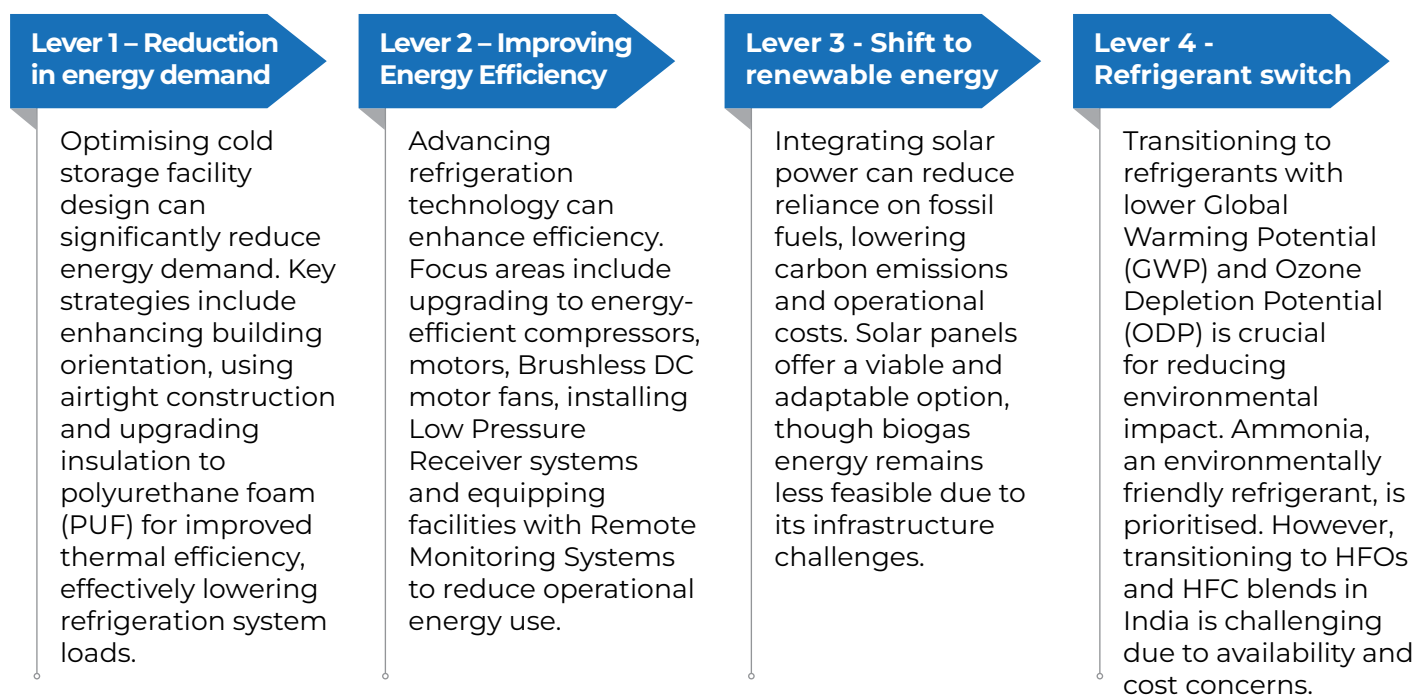
The journey towards energy-efficient technologies in cold chain logistics presents both challenges and opportunities. On one hand, old infrastructure leads to high energy consumption and operational costs, presenting financial burdens to facility owners and farmers. On the other hand, transitioning to the latest technologies offers the possibility of reducing environmental impact and operational inefficiencies. To navigate this transition successfully, stakeholders must address technological limitations, financial constraints, regulatory hurdles and gaps in technical expertise. India's cold chain infrastructure, despite its

importance, faces significant challenges in accommodating energy-efficient practices. The current system handles about 10% of the country's fresh produce needs, which underscores the urgency for improvement. Barriers such as high upfront investment costs, inadequate grid power supply, limited availability of low-GWP refrigerants, and a lack of standardised operations hinder progress. Overcoming these obstacles is vital for unlocking potential market growth and job creation within the sector.



Strategies for the implementation of energy transition

Short-term strategies focus on immediate actions, from 2025 to 2031. These involves four levers for energy transition:



‘Conventional scenario’ and ‘Energy transition scenario’ under the short-term energy transition implementation

- Conventional scenario:** This study defines the conventional scenario as a projection of current trends and practices in the Indian cold chain sector through 2031. This includes maintaining the existing utilisation capacity of cold chain components and energy consumption per tonne of produce.
- Energy transition (ET) scenario:** The ET scenario explores the impact of implementing energy saving measures (ESMs) and integrating renewable energy (RE) into the cold chain infrastructure. This scenario projects a reduction in grid electricity and diesel consumption and its associated CO₂ emissions. The ET scenario anticipates significant advancements in energy efficiency and renewable energy integration within the cold chain sector.



National-level energy transition potential – 2025 to 2031

Under this study, the study teams assessed the energy transition potential from 2025 to 2031 scenarios as part of immediate or short-term measures. For long-term measures, beyond 2031, the study team identified several recommendations, which are detailed in section 8.2 below. Below are some of the key findings from the assessment of the three perishables in three states when extrapolated at the national level. The energy and emission reduction estimations rely on the site visit assessments and identification of potential energy-saving measures across the CCI.

- **Potential energy demand reduction:** Energy transition measures could reduce total energy demand from a projected 6,245 GWh to 5,035 GWh, indicating enhanced energy efficiency.
- **Projected increase in renewable energy use:** Renewable energy contribution is anticipated to rise from 917 GWh to 1,078 GWh, suggesting a shift towards sustainable practices.
- **Projected energy savings:** Adoption of energy-saving measures is projected to yield annual savings of 876 GWh.
- **Projected emissions reduction:** Total emissions are forecasted to decrease significantly, with non-reefer emissions potentially reducing from 2,150 ktCO₂ to 1,409 ktCO₂, and reefer emissions from 438 ktCO₂ to 394 ktCO₂.
- **Overall emissions impact projection:** An estimated reduction of 785 ktCO₂ underscores the sector's potential contribution to national emission reduction goals.

Table ES3: Summary of scenario analysis

Parameters	Unit	Conventional 2031	ET 2031
Annual energy demand	GWh	6,245	5,035
RE penetration (Conventional vs ET)	GWh	917	1,078
Total annual energy savings through ESMs	GWh	NA	876
Total annual emissions without reefers (Conventional vs ET)	ktCO ₂	2,150	1,409
Total annual emissions - reefers (Conventional vs ET)	ktCO ₂	438	394
Total annual emissions impact (conventional vs ET)	ktCO ₂	NA	785

Immediate actions focus on implementing ESMs and RE solutions to address inefficiencies in India's largely privately-owned (over 90%) and fragmented cold chain infrastructure. ESMs, such as advanced insulation and energy-efficient refrigeration, combined with RE integration like rooftop solar, can reduce energy demand by approximately 1,057 GWh (22%) by 2031 compared to the conventional scenario, with potato storage facilities accounting for 75% of potential improvements. Rooftop solar could increase RE consumption by 160

GWh beyond current projections. Investments for ESMs are estimated at INR 1,135cr for potato storage in Uttar Pradesh and Gujarat, INR 77cr for chilli storage in Andhra Pradesh, and INR 3,000cr nationally for potato cold chain infrastructure (including solar PV). Accelerating RE adoption requires an additional INR 1,622cr for the Energy Transition (ET) scenario (30% RE penetration for packhouses/ripening chambers, 40% for bulk/hub storage) by 2031, with higher investments for an aggressive 40–50% penetration scenario.

Enabling energy transition in India's cold chain sector

India's cold chain sector, vital for reducing post-harvest losses and ensuring food security, faces challenges such as fragmented supply chains, high costs and limited adoption of sustainable technologies. This report outlines a phased approach to transform the sector through short-term (by 2031) and long-term (post-2031) recommendations, focusing on sustainability, efficiency and innovation.

2025–2031: The report calls for a coordinated national effort to modernize existing cold-chain assets, establish clear performance expectations, and build workforce capabilities, all supported by simple, consistent regulations and accessible financing. It emphasizes stronger planning to align capacity with the needs of producing and consuming states, along with reinforced first- and last-mile connections and upgraded refrigerated transport with digital visibility to reduce losses, fuel use, and downtime. It further recommends that all new facilities be future-ready—energy efficient, digitally capable, and built to common benchmarks in line with NCCD's revised Engineering Guidelines—while integrated regional hubs connect farm-gate pre-cooling, storage, and distribution to improve reliability and lower operating costs.

2032 and beyond: The document envisions a structural shift toward low-carbon, multimodal logistics with a greater role for rail, a mature transition to climate-friendly cooling technologies, and the seamless integration of cold-chain corridors within major food-processing ecosystems. It prioritizes interoperable systems, digitization, better shared data, and continuous innovation to deliver scale, reliability, and affordability, underpinned by stable policies and finance. The goal is a nationally connected, efficient, and climate-aligned cold chain that strengthens food security, raises farmer incomes, and supports sustainable growth.

Transforming India's cold chain is pivotal to sustainability, efficiency, and inclusive economic progress. The report sets a path to modernize and digitize assets, enable multimodal logistics, transition to climate-friendly refrigerants, and integrate infrastructure end to end, reinforced by skills, awareness, and streamlined standards. With stable policy support, targeted incentives, innovative financing, and collaboration, India can build a reliable, affordable, and climate-aligned cold chain that strengthens food security and farmer incomes while advancing national climate goals.





1. NCCD's Engineering Guidelines & Minimum System Standards 2025

The National Centre for Cold Chain Development (NCCD) has issued the 2025 Engineering Guidelines and Minimum System Standards for Implementation in Cold Chain Components (EG&MSS 2025), a landmark document that sets the benchmark for India's agricultural cold chain. These guidelines place strong emphasis on end-to-end integration—from farm-level production to market-level distribution—while embedding principles of technological advancement, modernization, sustainability, and energy efficiency. By consolidating global best practices and incorporating updated regulatory frameworks, EG&MSS 2025 not only addresses today's challenges but also establishes a future-ready framework for resilient cold chain development.

The revised guidelines simplify and standardize development processes with a sharp focus on eight core areas: Modernisation, Technology, Energy Efficiency, Refrigerants, Climate Responsiveness, Indigenous Manufacturing, Cold Supply Chain Strengthening, and Integrated System Design. A key achievement is their departure from outdated, energy-inefficient bunker coil systems—formally phased out in 2015—and their transition toward advanced, energy-conscious, and climate-compatible solutions.

A tiered model of facilities has been introduced to address the varied needs of India's agricultural ecosystem:

- **Farm Gate Packhouse:** Tailored for small farmers, these units enable hygienic handling, sorting, and safe storage immediately after harvest, protecting produce quality and value.
- **Farm Gate Standalone Cold Storage:** Optional small-scale cold rooms powered by solar, biomass, thermal storage, or grid electricity, providing flexible and sustainable storage solutions for unsold or overnight-held produce.
- **Integrated Packhouse:** Designed for larger farmers and aggregators, offering complete operations such as cleaning, washing, grading, pre-cooling, packaging, cooling, storage, and dispatch.
- **Collection and Aggregation Centres:** Equipped with advanced automation, sorting, grading, and energy-efficient cold rooms, these hubs connect farmer collectives (FPOs, cooperatives) to urban markets while extending produce shelf life.

The guidelines also redefine large-scale cold storage typologies (CS-1, CS-1-Onion, CS-2, CS-2-CA, CS-3, CS-4) by integrating low-GWP refrigerants, optimized insulation and building designs, and renewable-energy-ready technologies. Specialized applications such as Ripening Chambers and Controlled Atmosphere (CA) Rooms are emphasized for efficient handling of fruits and long-term storage of commodities like apples, ensuring product quality while minimizing energy intensity.

In continuation, a dedicated Energy Efficiency Sheet has been introduced along with a Basic Data Sheet. These instruments are designed to map the energy requirements and monitor consumption at the facility level. This structured approach enables systematic incorporation of energy efficiency measures and facilitates tracking of savings in terms of electricity units consumed, thereby ensuring accountability and promoting cost-effective operations.

Central to EG&MSS 2025 is the shift toward renewable and hybrid energy solutions. By actively encouraging solar, biomass, and thermal storage-based technologies, particularly for Packhouses and Aggregation Centres, the guidelines align cold chain infrastructure with India's climate commitments and sustainability goals.

Beyond infrastructure, the document highlights operational advancements such as dock levelling systems, automation, packaging innovations, and energy-efficient refrigeration technologies—positioning the sector for a digital, mechanized, and low-carbon future.

Importantly, this study on “Energy transition in the cold chain sector in India” reinforces that the sector is moving in the right direction. The study demonstrates how adoption of low-GWP refrigerants, renewable energy, and modern building technologies can drastically reduce the cold chain's carbon footprint without compromising performance. Together, the EG&MSS 2025 guidelines and the study provide a coherent roadmap, affirming that India's cold chain is not only addressing present inefficiencies but also preparing for a sustainable, energy-resilient future.

Ongoing Initiatives

The National Centre for Cold Chain Development (NCCD) is spearheading two landmark initiatives that will shape the future of India's cold chain sector: the Digitalization of Cold Chain Infrastructure and the All-India Cold Chain Infrastructure Census with Gap Analysis. These initiatives are not only critical to modernizing India's agricultural supply chain but are also validated in principle by the Energy Transition Study, which confirms that the sector is moving in the right direction towards energy-efficient, climate-resilient, and future-ready solutions.

Through its Digitalization Initiative, NCCD is transforming the sector from fragmented operations into a fully transparent, data-driven ecosystem. By integrating IoT-enabled sensors, automation, and centralized dashboards, stakeholders can monitor key parameters such as temperature, humidity, vehicle movement, and asset utilization in real time. This transparency enables administrators and policymakers to respond swiftly to disruptions and make evidence-based decisions. At the same time, a unified mobile booking platform for cold storage and transport is being introduced, ensuring farmers, producer organizations, and logistics operators have seamless access to cold chain services. By reducing underutilization of assets, transaction costs, and post-harvest losses, this initiative will directly enhance farmer incomes and ease of doing business.

Parallely, the All-India Infrastructure Census and Gap Analysis, launched in January 2025, is the first such exercise since 2014–15. Conducted by Hansa Research, the census will map cold storages, reefer transport, ripening chambers, controlled atmosphere units, and pharmaceutical storage. It is designed to capture data on infrastructure availability, technology adoption, energy use, refrigerant choices, and handling capacities, while identifying gaps in alignment with production clusters and market demand. The outcomes will be consolidated into an interactive district- and state-level dashboard, offering precise insights for policymakers, investors, and planners to prioritize future development.

While the results of these initiatives are still in progress, the Energy Transition Study provides an important validation: it confirms that digitalization, automation, low-GWP refrigerants, and evidence-based planning are indeed the pathways through which the cold chain can achieve sustainability,

efficiency, and resilience. In other words, these projects are not isolated efforts but form part of a coherent strategy already endorsed by the study's conclusions.

Taken together, these initiatives demonstrate how NCCD is not only revising standards and guidelines but also actively implementing forward-looking projects. By aligning infrastructure development with energy transition pathways, NCCD is ensuring that India's cold chain evolves into a modern, inclusive, and sustainable pillar of national growth—supporting farmers, reducing food losses, and advancing India's climate and food security commitments.





2. Introduction to the study

Agriculture is a cornerstone of India's economy, contributing significantly to employment, GDP and food security. As of 2023, agriculture accounts for approximately 18% of India's GDP and employs nearly 42% of the workforce, making it the largest source of livelihood for rural populations (Ministry of Finance, 2024). India is a global agricultural powerhouse, ranking as the world's second-largest producer of fruits and vegetables and a leading exporter of rice, wheat and spices. The sector supports allied industries such as food processing, textiles and exports, which generated USD 53.1 billion in agricultural export revenue in 2022–23 (Ministry of Commerce & Industry, 2024). Agriculture also ensures food security for India's 1.4 billion population, with programmes like the Public Distribution System relying on domestic production.

Despite its critical role, the agricultural sector faces challenges like low productivity, fragmented landholdings and significant post-harvest losses. Post-harvest losses represent a critical area for improvement. Post-harvest losses, particularly in fruits and vegetables, range from 5–15% annually, translating to an economic loss of approximately USD 13bn (Ranjan & Sahni, 2023). These losses occur due to inadequate storage, poor transportation, inefficient supply chains and suboptimal handling practices. Reducing post-harvest losses can enhance India's economic growth, improve food security and boost rural livelihoods in the following ways:

- **Increased economic output:** By minimising losses, more produce reaches markets. This increases the availability of goods for domestic consumption and export. For instance, reducing losses in fruits and vegetables by 10% could save USD 1.3 billion annually, strengthening the agricultural GDP contribution (FAO, 2022). This additional revenue can be reinvested into rural infrastructure and technology.
- **Enhanced farmers' incomes:** Post-harvest losses directly reduce farmers' earnings, particularly for smallholders who dominate India's agricultural landscape. Improved storage, such as cold chains and Zero Energy Cool Chambers, and transportation, such as refrigerated lorries, ensure a higher marketable surplus. This can potentially increase farmers' incomes by 20–30% for perishable crops (ICAR, 2024). Initiatives like the Kisan Rail and PM Kisan Sampada Yojana are already facilitating better market access.

- **Strengthened food security:** According to the NFHS-5, in India, 35.5% of children under five are stunted, 19.3% are affected by wasting, and 32.1% are underweight. Additionally, the Global Hunger Index states that 13.7% of India's population is undernourished, which the Government of India claims is higher than actual number due to the low sample size. Reducing post-harvest losses can ensure that more nutritious food reaches consumers. Enhanced supply chain efficiency can lower food prices. This makes fruits and vegetables more accessible to low-income households, thus addressing dietary deficiencies.
- **Environmental sustainability:** Post-harvest losses waste resources like water, energy and labour used in production. Reducing losses aligns with sustainable development goals by optimising resource use and reducing food waste. Food waste accounts for 8–10% of global greenhouse gas emissions (FAO, 2022).

Food loss and waste occur at every stage of the supply chain, driven by infrastructural limitations, economic constraints and inefficient practices. At the farm level, inadequate storage, transportation and packaging contribute to losses. Consumer behaviours, including overbuying and improper storage, further compound the issue. Addressing this complex challenge demands a multifaceted approach: empowering farmers, investing in modern infrastructure, strengthening market links and raising consumer awareness. By harnessing innovation, collaboration and strategic investments, India can transform its food system, ensuring equitable access to nutritious food while setting a global example for sustainable progress.



2.1. Role of cold chain infrastructure in post-harvest management

A reliable and integrated cold chain is crucial for ensuring food security, preserving freshness and safety, and enhancing agricultural efficiency in India. Encompassing the entire spectrum of refrigerated production, storage, transportation and distribution processes, the cold chain collectively aims to maintain the optimal temperature and freshness of perishable goods. Given India's status as a leading global producer of fruits and vegetables, the cold chain plays an indispensable role in minimising post-harvest losses and preserving the quality and nutritional value of produce. A cold chain system effectively manages the product's post-harvest journey from the field, through various nodes including collection, packing, processing, storage, transport and marketing, until it reaches the end consumer. Any disruption in this chain, known as a cold chain break, can compromise food safety and lead to significant losses.

Despite significant advancements in India's cold chain sector in recent years, it remains fragmented and inefficient, with most of the infrastructure concentrated near urban and semi-urban areas. This fragmentation results in issues such as supply chain inefficiencies, unequal economic development, limited market access and challenges in meeting demand fluctuations. Consequently, the primary objective of reducing post-harvest losses is compromised. Addressing these losses requires innovative, scalable and sustainable solutions across the cold chain.

Below are some key post-harvest solutions, focusing on technology, infrastructure, practices and policy interventions, tailored to the context of India and similar regions that may help address the challenge of post-harvest losses.

Policy and market interventions

- **Subsidies and incentives:** Government subsidies for cold storage, solar dryers, or packaging materials can encourage adoption among smallholder farmers. India's Mission for Integrated Development of Horticulture (MIDH) provides financial support for such technologies.
- **Market linkages:** Strengthen direct-to-consumer models, such as FPOs and e-commerce platforms, to reduce intermediaries and ensure fresher produce reaches markets. Platforms like Ninjacart and BigBasket bridge this gap.

Improved storage technologies

- **Cold chain infrastructure:** Expanding access to cold storage facilities is critical for perishable goods like fruits and vegetables. Modular cold storage units, powered by solar energy, could be deployed in rural areas to reduce spoilage. For example, initiatives like India's Cold Chain Integrated Network aims to establish temperature-controlled warehouses near farms.
- **Low-cost alternatives:** For smallholder farmers, technologies like Zero Energy Cool Chambers (ZECC)—evaporative cooling systems made from bricks and sand—could extend shelf life at minimal cost. These prove particularly effective in remote areas with limited electricity.
- **Controlled atmosphere storage:** Using controlled environments to regulate oxygen, carbon dioxide and temperature could significantly prolong the freshness of produce. This proves ideal for high-value crops destined for export or urban markets.

Enhanced transportation systems

- **Refrigerated transport:** Investment in refrigerated trucks and rail systems can ensure that produce remains fresh during transit. Public-private partnerships, like those under India's Kisan Rail initiative, have introduced climate-controlled transport for agricultural goods.
- **Smart logistics:** IoT-enabled tracking systems can monitor temperature and humidity in real time during transportation, reducing spoilage due to mishandling. Startups in India, such as Tessol, deploy plug-and-play thermal storage solutions for last-mile delivery.
- **Localised distribution:** Establishing regional aggregation centres near production hubs minimises transit time and reduces losses from long-distance transport.

Post-harvest processing and value addition

- **Minimal processing:** Techniques like washing, sorting and pre-cooling immediately after harvest can preserve quality. Mobile processing units can be deployed to farms, enabling on-site preparation.
- **Value-added products:** Converting surplus or cosmetically imperfect produce into products like dried fruits, juices, or frozen goods prevents waste. For instance, India's food processing sector expands under schemes like PM Kisan Sampada Yojana, which supports processing infrastructure.
- **Dehydration and solar drying:** Low-cost solar dryers can preserve fruits and vegetables in regions with abundant sunlight. This will reduce dependence on energy-intensive methods.

Training and capacity building

- **Farmer education:** Training farmers on best practices for harvesting, handling and storage can significantly reduce losses. Extension services, supported by organisations like the Indian Council of Agricultural Research (ICAR), are scaling up outreach through digital platforms and local cooperatives.
- **Women empowerment:** In many rural areas, women manage post-harvest activities. Targeted training programmes for women can improve efficiency and promote gender-inclusive growth.
- **Digital tools:** Mobile apps providing real-time advice on post-harvest management, market prices and weather conditions empower farmers to make informed decisions. Apps like KrishiHub are gaining popularity in India.

2.2. About the study

This study aims to understand the current landscape of the cold chain sector and identify opportunities for sustainable development of the cold chain sector by developing a national-level energy transition roadmap for the sector.

Developing an energy transition roadmap for India's cold chain sector is crucial to ensure sustainable growth that aligns with the country's environmental and energy goals. As the sector expands to support the nation's significant agricultural output, it poses a potential strain on the electricity grid and risks increasing carbon emissions. By promoting the uptake of clean energy sources, such as solar and wind power, alongside energy-efficient technologies and practices, the roadmap can mitigate these issues. This strategic approach not only helps in reducing the sector's carbon footprint but also enhances energy efficiency, lowering operational costs and fostering innovation. Additionally, it ensures that the sector's development contributes positively to national energy security and independence, supporting broader climate commitments and economic growth objectives.

Study objective

The objective of the study is to evaluate the current cold chain landscape in India through a detailed cold value chain assessment of three perishables. It will critically analyse the potential for energy transition and subsequently develop an energy transition roadmap at the national level. As 80% of India's current cold chain infrastructure is dedicated to horticultural produce (NCCD, All India Cold-chain Infrastructure Capacity (Assessment of Status & Gap), 2015), the study predominantly covers the agriculture cold chain sector. The specific objectives are as follows:

- **Objective 1:** Cold Chain Infrastructure Assessment: Evaluate the existing cold chain infrastructure in India, including storage facilities, transportation networks and processing capacities. Analyse the growth trajectory of this infrastructure, identify existing gaps and project future needs based on anticipated growth in the perishables sector.
- **Objective 2:** Perishable Product Landscape Analysis: Conduct an analysis of the perishables sector in India. This includes identifying key perishable products, mapping their movement from farmgate to market and selecting three representative perishables across three different states for in-depth case studies.
- **Objective 3:** Energy Transition Roadmap: Based on the insights gained from Objectives 1 and 2, develop a comprehensive roadmap for energy transition in the Indian cold chain sector. This roadmap includes:
 - Recommendations for transitioning to energy-efficient technologies and renewable energy sources.
 - Strategies to address infrastructure gaps and improve the efficiency of existing systems.
 - Policy recommendations to incentivise sustainable practices and attract investment in cold chain development.

This report is structured to provide a comprehensive analysis of the post-harvest cold chain landscape in India. Section 1 and 2 provide the rationale for developing this study, Section 3 establishes the study's context, objectives and methodology. Section 4 offers an overview of the current infrastructure, policy landscape, technological advancements and energy consumption in the cold chain sector. Section 5 provides an overview of the global trends and practices in the cold chain sector and its relevance to the Indian context. Section 6 assesses the broad level perishables landscape in India, while section 7 deep dives into the detailed analysis of the cold supply chains of three specific perishable. Section 8 provides the key takeaways of the assessment, Section 9 examines opportunities for energy transition, detailing potential benefits and an implementation strategy. Finally, Section 10 concludes the report with recommendations based on the findings.

Study methodology

The study involves a three-fold methodology involving a literature research, stakeholder consultations and field visits.

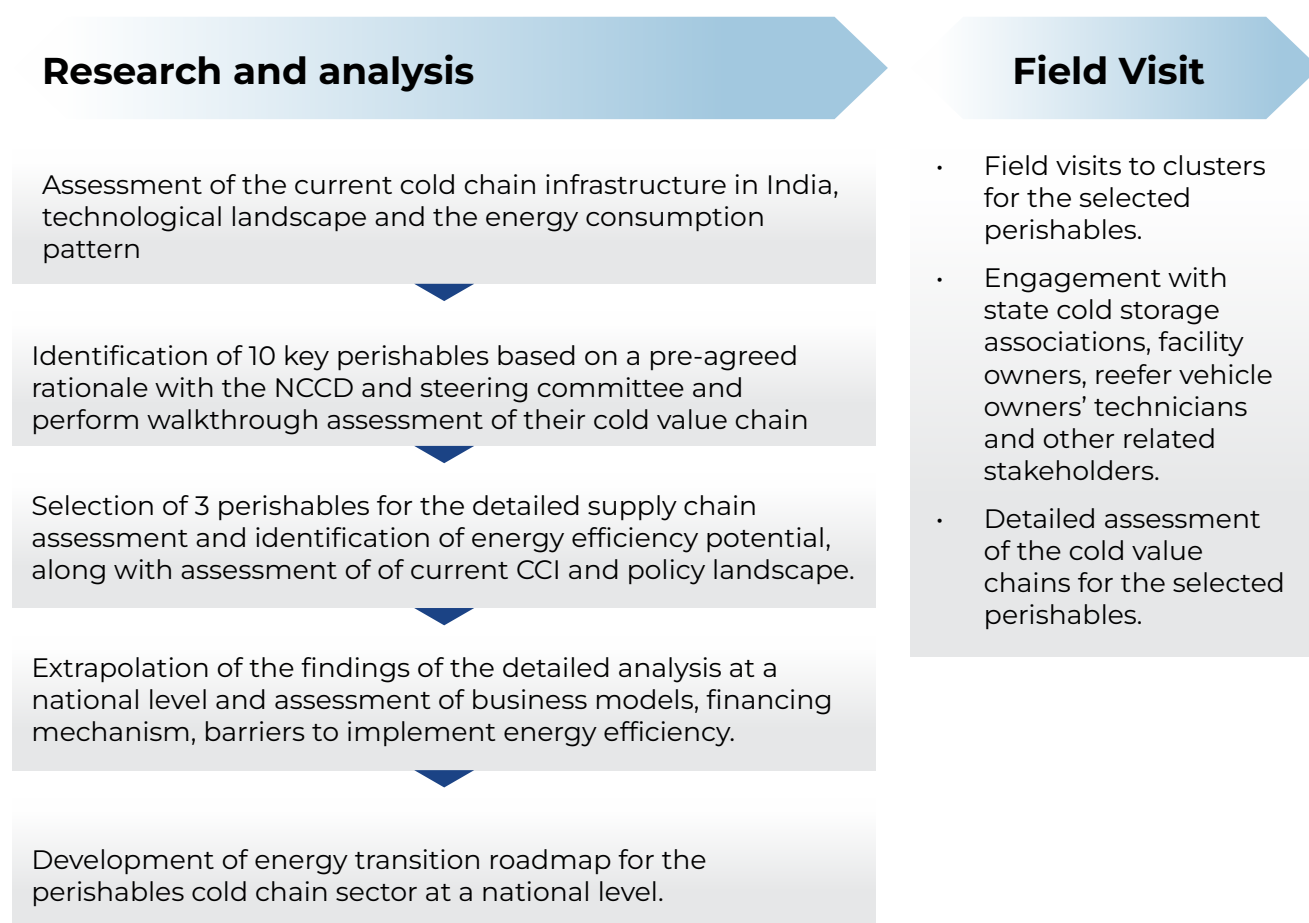
Literature research and analysis provides a solid foundation by offering existing knowledge and data on the current state of cold chain infrastructure, the dynamics of the perishables sector and potential energy transition strategies. By reviewing previous studies, reports and analyses, researchers can identify gaps in infrastructure, understand movement patterns of key perishable products, and explore energy-efficient technologies and renewable energy sources that could be applicable.

Stakeholder engagement is essential for gathering firsthand insights and practical perspectives from individuals directly involved in the cold chain sector, including government officials, industry leaders, farmers, distributors and facility operators. These interactions provide valuable information on operational challenges, logistical processes, regional variations and barriers to adopting sustainable practices. They help validate findings from literature research and ensure that recommendations are grounded in real-world experiences and challenges faced by stakeholders.

Field visits complement the research process by allowing direct observation of cold chain facilities, including storage, transportation and distribution networks. By visiting farms, processing sites and markets, researchers can assess infrastructure conditions, identify practical challenges, and observe the actual movement and handling of perishables across different regions. Field visits provide empirical data that enhance the understanding of logistical and energy challenges, directly informing the development of a comprehensive energy transition roadmap.

Together, these methodologies ensure a comprehensive approach to evaluating the current landscape of the cold chain sector, analysing the movement and handling of perishable goods. They also craft an energy transition roadmap with actionable recommendations. These include the adoption of energy-efficient technologies and renewable sources, the addressing of infrastructure gaps and the incentivisation of sustainable practices to attract investment in cold chain development.



Figure 1 : Study methodology

Stakeholder engagements: Engagements conducted throughout the lifecycle of the project with technology providers, cold chain consultants, reefer owners, chartered accountants, and ISHRAE regional chapters to support and validate the research conducted

Note:

- While this report leverages extensive literature research and stakeholder consultations to provide a comprehensive overview of India's cold chain infrastructure, it is important to acknowledge that the National Centre for Cold-chain Development (NCCD) is currently undertaking a significant data revision process.
- As an autonomous body under the Ministry of Agriculture and Farmers' Welfare (MoAFW), the NCCD's updated figures, expected in 2026, will supersede the data presented herein and offer the most accurate representation of India's cold chain infrastructure landscape.

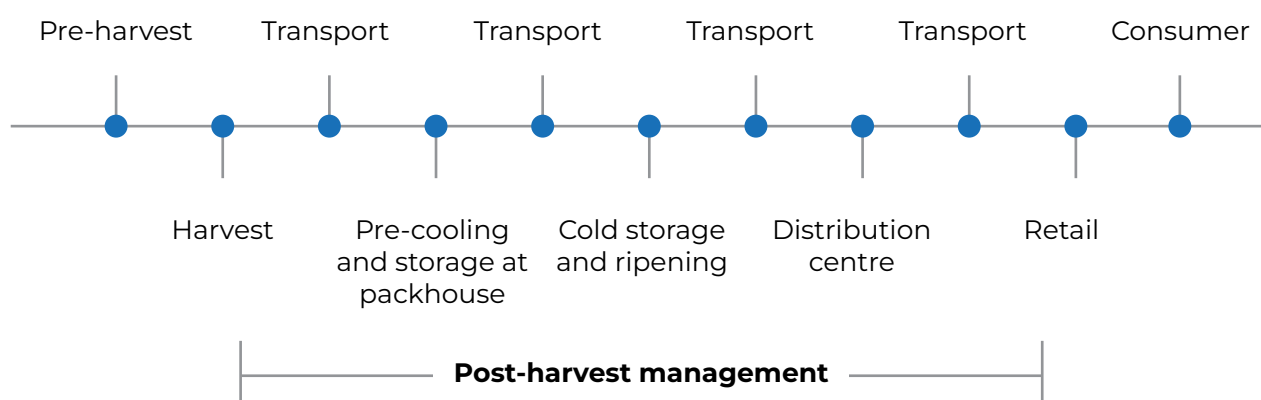


3. Indian Cold Chain Sector Landscape

To develop an effective energy transition roadmap for the cold chain sector in India, it is crucial to first gain a comprehensive understanding of the current landscape of this sector. This analysis serves as a foundational step towards identifying opportunities for improvement, comprehending the challenges that hinder progress, and establishing a practical implementation pathway

for energy transition within the sector. Figure 2 below illustrates a general supply chain for agricultural perishables in India. The main components of a post-harvest cold supply chain in India are packhouses, cold storage (bulk and hub), ripening chambers, processing facilities, and refrigerated vehicles. Processing facilities are not included in the scope of this study.

Figure 2: General cold supply chain of agricultural perishables



A typical post-harvest supply chain can be segregated into three stages – farmgate level, mid-level and the distribution level. The farmgate level usually consists of micro cold storage infrastructure like solar cold rooms with capacity mostly ranging between 5-30MT, and standard packhouses, used for initial sorting and grading of the harvested produce. The mid-level in the post-harvest supply chain contains the highest concentration of cold storage infrastructure. This

usually consists of bulk and hub cold storages, along with ripening chambers and CA cold rooms. The final level is the distribution level, which comprises the distribution centres, dark stores and retail outlets. It is important to note that cold storages (bulk/hub) can form a part of both, mid and distribution levels of the post-harvest due to the highly fragmented supply chain in India. Section 4.1 below examines each component of the cold chain sector and its significance.



3.1. Type of cold chain components in India's post-harvest sector

India's post-harvest agricultural sector is notably skewed (covered in section 4.2 below) and is primarily dominated by single-commodity cold storages. A striking 75% (MoFPI, Opportunities in the Cold chain Sector in India, 2016) of India's cold storage infrastructure is dedicated to the storage of potatoes. This reflects the market demand and agricultural focus on this staple crop. Other bulk-stored perishables, such as chillies and onions,

also occupy significant portions of cold storage capacity. However, the presence of comprehensive cold chain components for a diverse range of perishables is comparatively limited, highlighting a critical area for development.

Table 1 provides a comprehensive overview of key cold chain infrastructure types observed in India's post-harvest sector, detailing their applications.

Table 1: Agricultural post-harvest cold chain infrastructure components

Component	Sub-component	Supply chain level	Description
Packhouses	Packhouse – standard	Farmgate level	Facilities where agricultural products are cleaned, sorted, graded and packed, typically without additional refrigeration or cooling capabilities.
	Packhouse - integrated with precooling and staging cold rooms	Farmgate/mid-level	Packhouses that include precooling units and cold rooms for staging, allowing produce to be rapidly cooled to preserve quality and extend shelf life before further storage or transport.
Cold Storages	Cold storage bulk - single commodity (Type 1)	Mid-level/distribution level	Large storage facilities designed primarily for a single commodity, such as potatoes, to maintain consistent temperature and humidity levels suitable for long-term bulk storage.
	Cold storage – (Type 4)	Mid-level/distribution level	Cold storage facilities specifically used for storing dry commodities like chilli, spices, lentils and similar products, where a controlled environment is maintained to preserve quality.
	Cold storage hub - multi commodity (Type 2)	Mid-level/distribution level	Centralised cold storage facilities equipped to handle multiple commodity types, offering flexible storage solutions for a diverse range of perishable goods.
	Cold rooms at farmgate level	Farmgate level	Refrigerated storage units located at the farm level, designed to maintain freshness and quality immediately after harvesting, before products enter broader supply chains.

Component	Sub-component	Supply chain level	Description
	Controlled Atmosphere (CA) stores	Mid-level	Advanced storage facilities that regulate temperature, humidity and gas composition to extend the shelf life of specific produce by slowing down ripening and decay processes.
Ripening chambers	Ripening rooms (Type 3)	Mid-level	Facilities that use controlled environments, such as temperature and ethylene gas, to manage and accelerate the ripening of produce, like bananas and mangoes, ensuring uniform quality and readiness for market.
Refrigerated transport	Reefer vehicles	Applicable to all levels	Refrigerated transport vehicles specifically designed to move perishable goods over roadways, ensuring temperature control throughout transit.
	Refrigerated cargo containers	Distribution level	Insulated and temperature-controlled containers used for shipping perishables via sea, ensuring longevity and quality during longer transport durations.
	Cool rail wagons	Distribution level	Rail transportation units equipped with refrigeration capabilities, facilitating the movement of perishable goods over long distances by rail while maintaining necessary temperature conditions.

Note:

- Type 1, 2, 3, and 4 are terminologies established under the 'Engineering guidelines & minimum system standards for implementation in cold chain components'. Please refer to the document for more information related to the nomenclature.

3.2. Indian cold chain infrastructure growth projections and regional spread

Cold chain sector in India has gained traction and is projected to grow significantly over the next few years. The current CAGR growth estimates are not officially available, however, based on the infrastructure numbers available for the past

years, the approximate CAGR has been calculated, which is shown in Table 2 below. The projected CAGR estimates may or may not represent the actual growth rate till 2031.

Table 2 Cold chain infrastructure growth

	Unit	2015	2020	2024	2031	Estimated CAGR
Packhouse	Nos	249	675	1,312	4,201	18.08%
Cold Storage (Bulk)	Lakh MT	239	273	296	345	2.18%
Cold Storage (Hub)	Lakh MT	64	73	79	92	2.18%
Ripening Chambers	Nos	812	1,232	1,627	2,646	7.20%
Reefer Vehicles	Nos	9,000	14,263	19,388	33,176	7.98%

Notes:

- 2015 numbers are sourced from the NCCD study on infrastructure gap assessment (NCCD, 2015).
- Values for 2020 are sourced from the study carried out by the World Bank in 2020 (Efficiency for Access Coalition, 2023)
- Values for 2024 and 2031, for the components except cold storages, are estimated by extrapolating the numbers of 2015 and 2024 numbers.
- Cold storage capacities are estimated using the assumptions made based on the site visits and stakeholder consultations and using the economic parameters such as population growth.
- NCCD is currently conducting a study to identify the exact number of cold chain infrastructure in India. The above-mentioned numbers are based on the previous growth trends and their CAGR estimates. The cold chain infrastructure which will be published by the NCCD in their latest report will supersede the numbers mentioned in this report.
- 75% of the cold storage capacity has been accounted for bulk facilities, 20% for hub facilities and the remaining 5% has been accounted for other cold storages like pharmaceuticals etc. Hence the actual cold storage number for 2024 (395 LMT) mentioned in section 4.2.2 is not being reflected in the table above.

The availability and distribution of cold chain infrastructure in India are closely tied to the agricultural output of each state, as regions with higher production of perishable goods require more extensive facilities to store, process and maintain the quality of these products. The following sub-sections highlight the broad level regional spread of the cold chain components across the country.

Packhouse

In India, the number of packhouses is relatively small compared to the number of cold storage facilities. Packhouses are primarily located in states with significant fruit production and export activities. According to the Agricultural and Processed Food Products Export Development Authority (APEDA), there are currently 206 registered packhouses in the country. However, this figure differs from the number reported by the 2015 report, 'Assessment and Gap in Cold Chain Infrastructure', which recorded 249 packhouses at that time. Another report, developed by the World Bank and the Alliance for Energy Efficient Economy, stated that there were around 500 packhouses

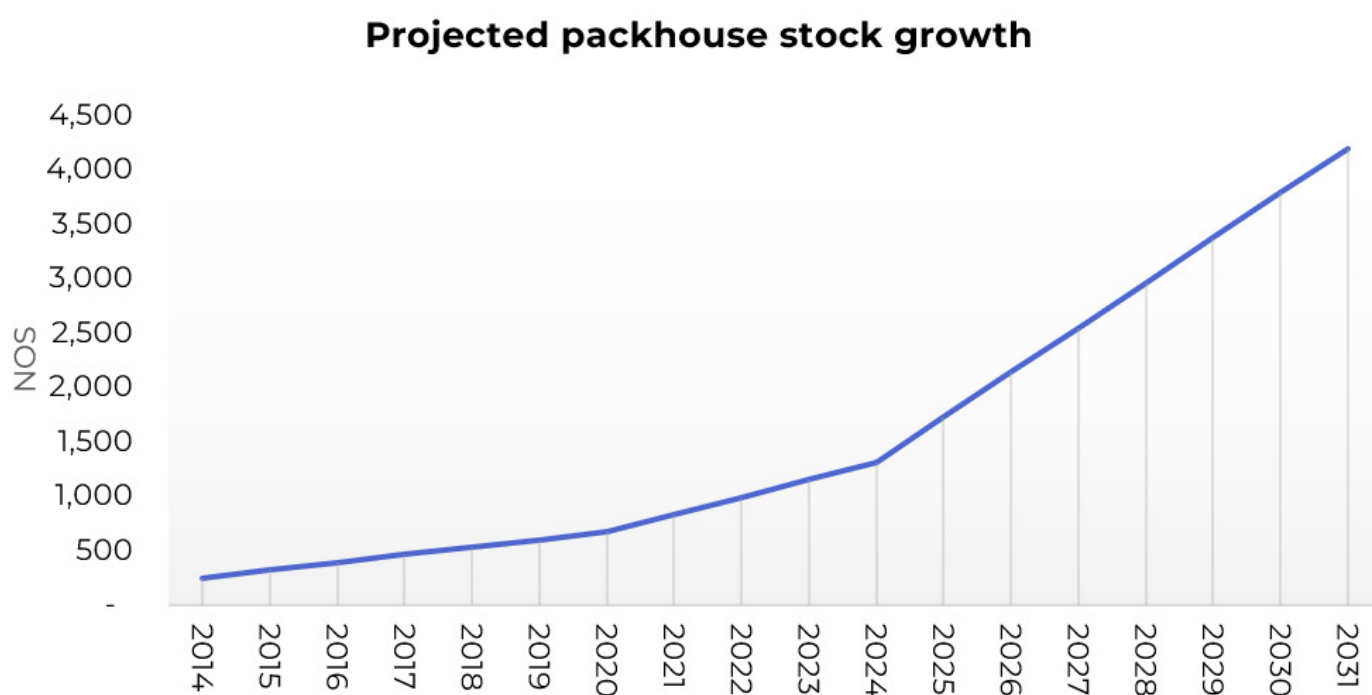
in India in 2019 (AEEE, 2022). All aforementioned packhouses are integrated packhouses only. The total number of on-farm packhouses, also called as standard packhouses, exceed 20,000, as of 2018 (MoAFW, 2018). It is mandatory for all export-oriented packhouses to register with APEDA, while the non-export packhouses may or may not register with APEDA. Table 3 below highlights the top states in India with the highest number of APEDA-registered packhouses, from an export perspective. The exact state-wise distribution of standard packhouses and non-export-oriented integrated packhouses is currently unavailable with government authorities.

Table 3: State wise APEDA registered packhouses

State	APEDA registered packhouse	% of India's packhouses
Maharashtra	144	70%
Gujarat	13	6%
Tamil Nadu	10	5%
Uttar Pradesh	9	4%
Andhra and Telangana	9	4%
Others	21	11%
Total	206	100%

Figure 3 below illustrates the projected exponential growth in the number of integrated packhouses in the country. This trajectory is driven by a 47.3% (MoCI, 2025) increase in fruit and vegetable exports

over the past three years and entry into three new markets. With a strong forecast, this cold chain infrastructure is expected to receive a significant boost in the coming years.

Figure 3 Packhouse expected growth trajectory

Source: Author analysis

Cold storages

Cold storages have the highest concentration of any cold chain infrastructure in the country, especially the Type 1 bulk cold storages, which are used for potato storage. Uttar Pradesh has the highest concentration of cold storages in the country owing to its agricultural output, which is the highest in India. Detailed state-wise agricultural output is discussed in Chapter 6.

As of May 2024, India has 8,698 cold storage facilities, (including Type 1, 2 and 4 facilities),

corresponding to 395 lakh MT in capacity. In terms of the warehousing capacity, Uttar Pradesh has the highest capacity, while Maharashtra takes the top position in terms of processing capacity, leading due to its industrial prowess and export orientation. The top ten states mentioned in Table 4 (MoFPI, 2023) (NCCD, 2024) account for approximately 90% of India's total capacity and 82% of the total number of India's cold storage facilities.

Table 4: Availability of cold storages by application as of May 2024

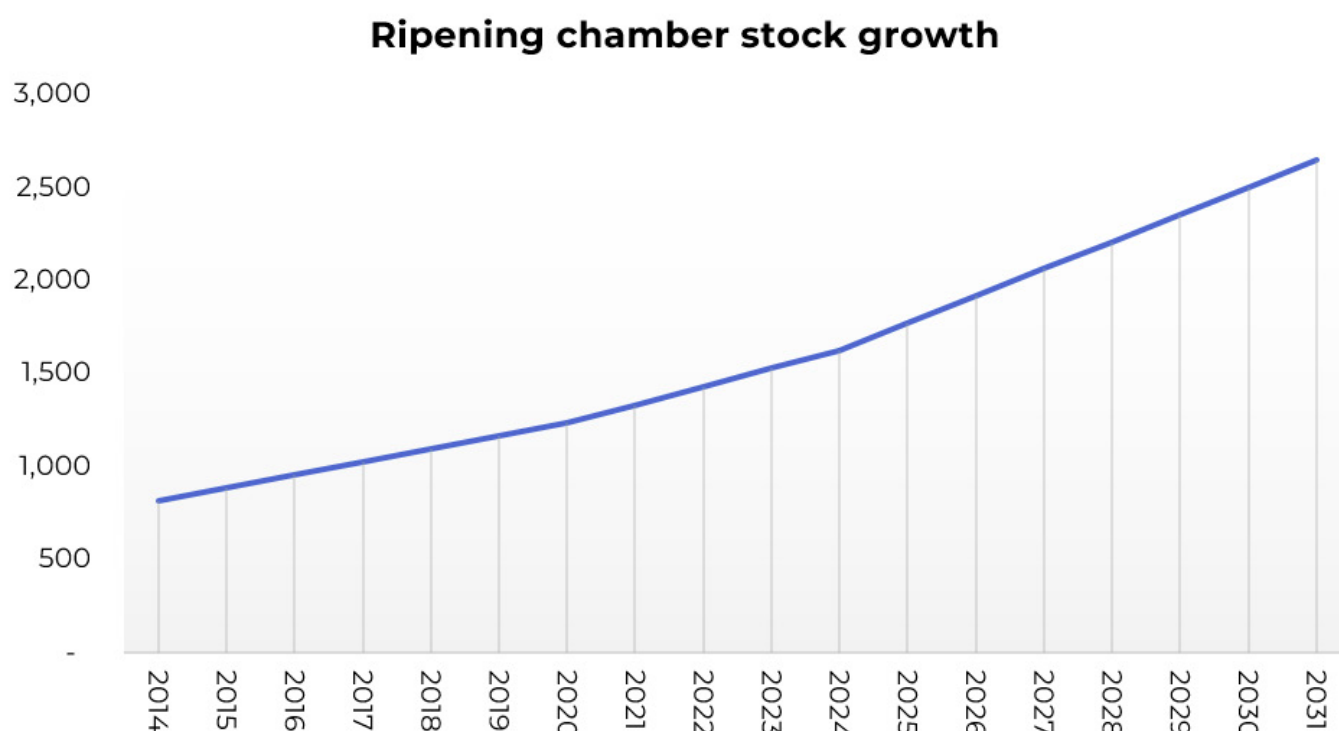
Rank	State	No. of facilities	Installed capacity (Lakh metric tonne)		
			Food processing	Storage	Total
1	Uttar Pradesh	2,481	0.78	150.22	151.00
2	West Bengal	517	0.70	58.80	59.50
3	Gujarat	1,023	0.49	39.91	40.40
4	Punjab	770	0.16	25.84	26.00
5	Andhra Pradesh & Telangana	471	0.73	18.37	19.10
6	Bihar	315	0.44	14.36	14.80
7	Madhya Pradesh	315	0.35	13.25	13.60
8	Maharashtra	655	1.89	9.81	11.70
9	Haryana	380	0.58	8.12	8.70
10	Karnataka	261	0.33	8.17	8.50

Ripening chambers

Ripening chambers, like packhouses, are not widely present across the country. However, their numbers are increasing gradually. As of 2024, estimates indicate that there are over 1,600 ripening units across the country. In comparison, there were 812 ripening units in 2015, and by 2020, the number had risen to an estimated 1,232 units. Ripening chambers only apply to climacteric fruits like mangoes and bananas, on which ethylene acts. Non-climacteric fruits like grapes, pineapple, etc. do not show any react to ethylene and are therefore not stored in ripening chambers. Currently, the ripening business in India focuses largely on bananas and, to some extent, mangoes.

Andhra Pradesh stands out as the largest banana-producing state, followed by Maharashtra and Karnataka. Consequently, these states exhibit a higher concentration of ripening chambers. This distribution aligns with government initiatives, as substantial budgets are allocated for developing ripening infrastructure in these major banana-producing regions (MoAFW, 2016).

Figure 4 below illustrates the projected growth trajectory of ripening chambers in India, showing a predominantly linear increase until 2031. To expand this infrastructure further, other climacteric fruits and vegetables, such as avocados and tomatoes, can also be considered.

Figure 4 Ripening chamber growth trajectory

Source: Author analysis

Refrigerated transport

Refrigerated transport vehicles form an integral part of an integrated cold supply chain. However, their utilisation has not reached its full potential. In India, these vehicles are predominantly used for export-oriented perishables and those requiring very low temperatures for storage. The dairy and processed foods industries have experienced a significantly higher uptake of refrigerated vehicles. As of 2024, estimates suggest that there

are approximately 19,000 reefer vehicles in India, compared to about 9,000 in 2015, according to the NCCD's Assessment and Gap in Cold Chain Infrastructure report. However, no available estimates indicate the percentage distribution of these vehicles across various applications. Most reefer vehicles in India are concentrated in tier-1 and tier-2 regions, as well as in export-oriented areas like ports, as highlighted below in Figure 5.



Figure 5 Concentration of reefer vehicles in India

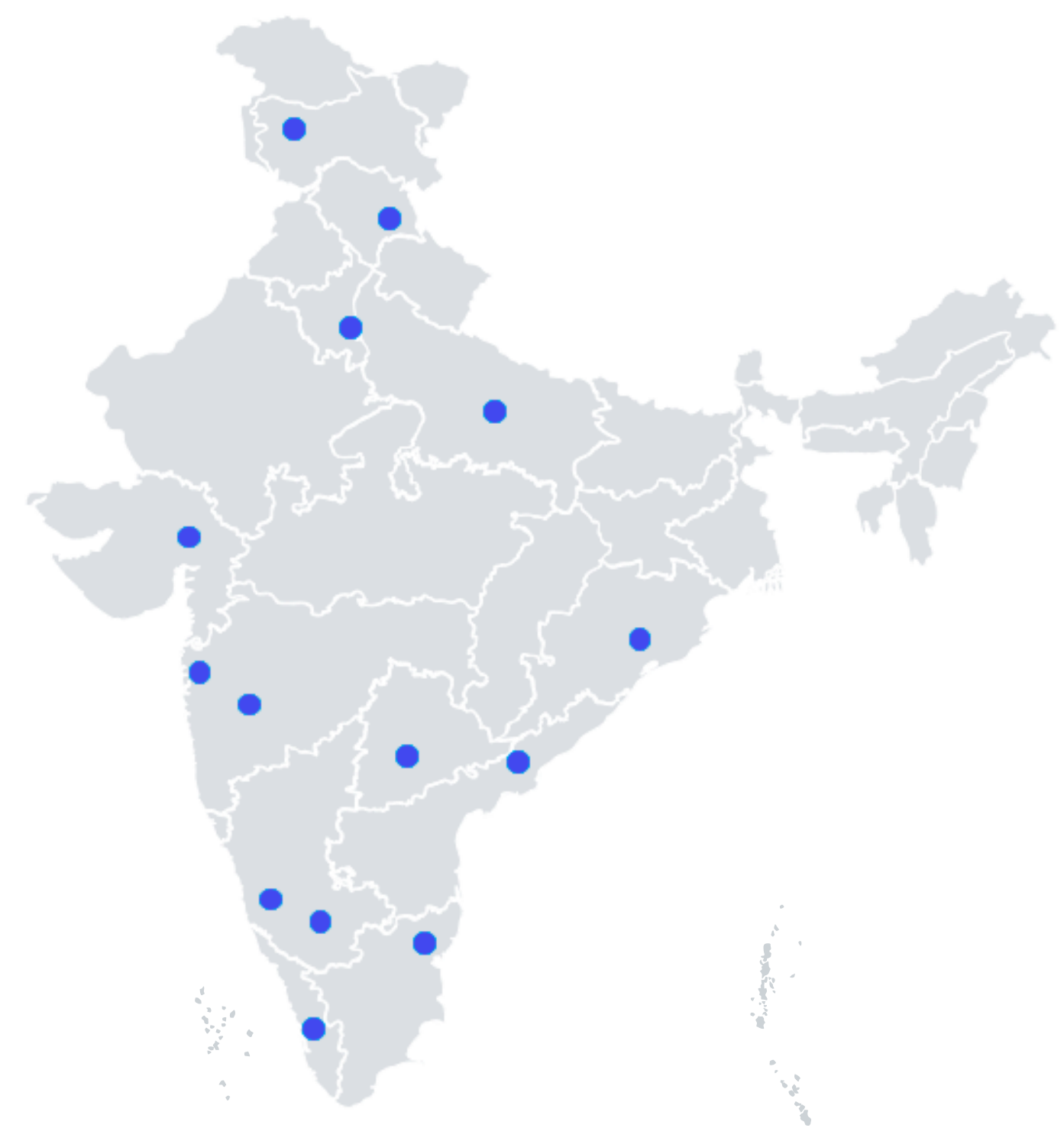
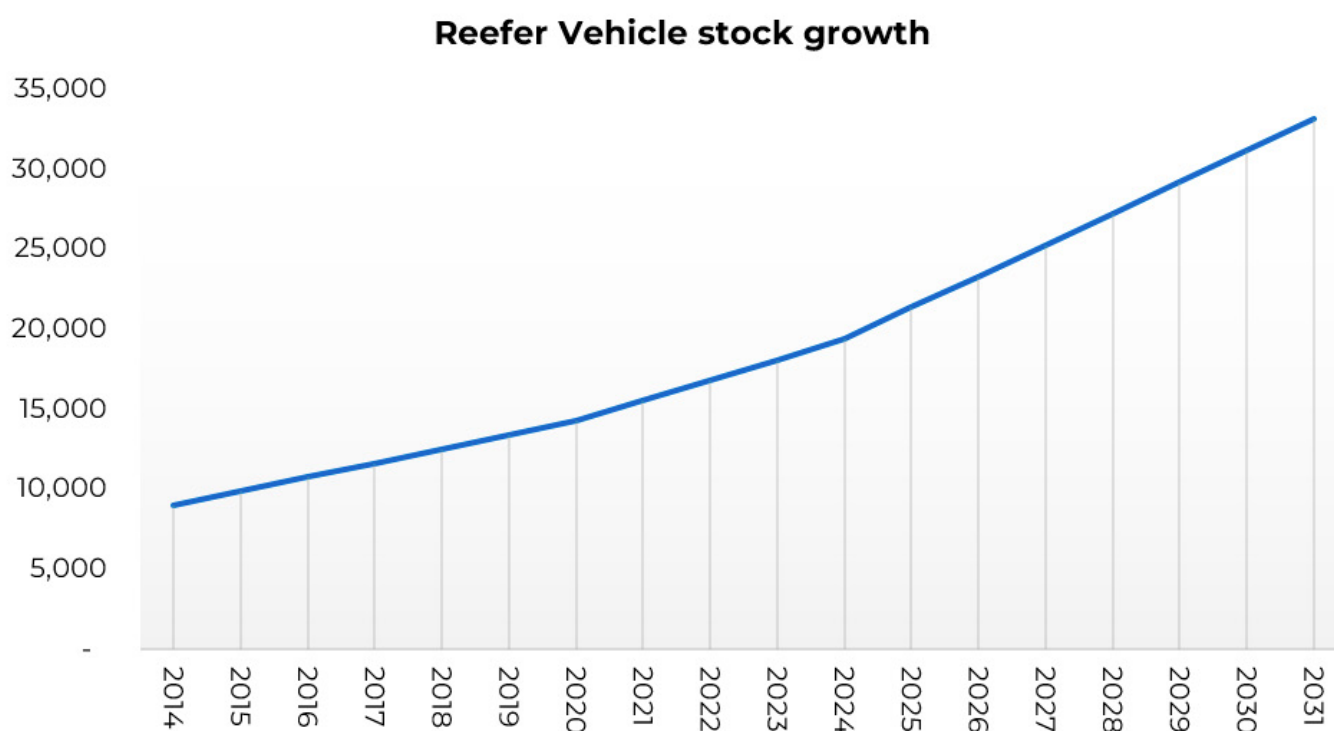


Figure 6 below illustrates the projected growth trajectory of reefer vehicles in India, showing a primarily linear increase until 2031. These year-

on-year growth numbers are based on the CAGR estimates presented in Table 2 above.

Figure 6 Reefer vehicles growth trajectory

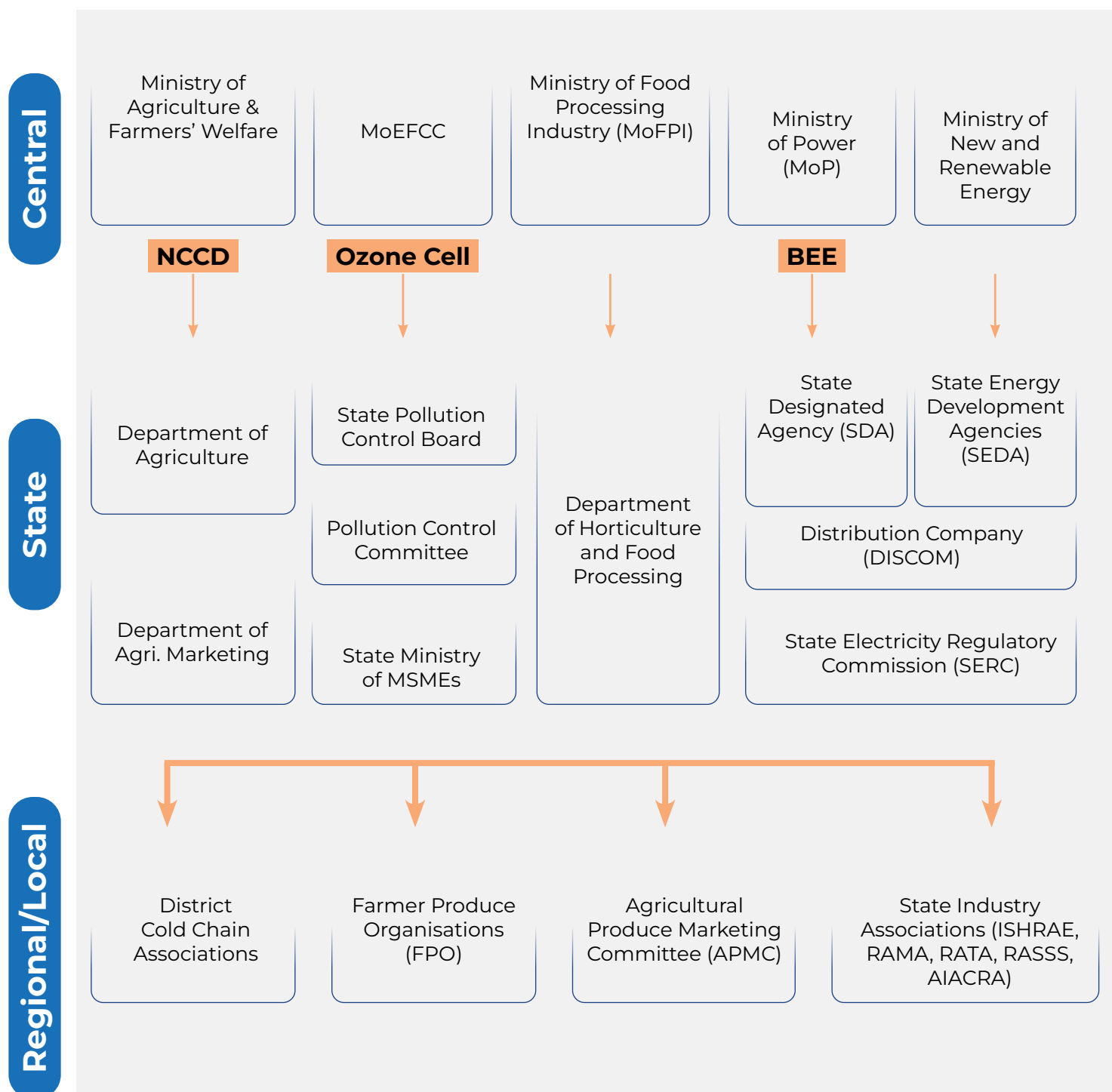


Source: Author analysis

3.3. Cold chain policy landscape in India

The development of an energy transition roadmap for India's cold chain sector is intricately linked to the prevailing policy landscape. As the cold chain sector is poised for expansion, policies provide the essential framework, guiding principles, and incentives necessary to support sustainable growth and align the sector with broader national objectives for environmental stewardship and economic advancement. In India, the development of cold chain infrastructure is a collaborative effort involving both the central and state governments.

It is driven by policy initiatives at national and state levels, reflecting the necessity for tailored approaches to address regional needs and opportunities. The cold chain sector encompasses multiple agencies and entities, requiring a synergy of competencies to create a cohesive and efficient infrastructure. Figure 7 below illustrates various agencies and departments that are actively contributing to the maintenance and growth of sustainable cold chain infrastructure in the country.

Figure 7: Role of policy in driving cold chain infrastructure and food security in India


Source: Author compilation

Role of Central Government

The Central Government of India plays a pivotal role in policy development for the cold chain sector, serving as the primary architect of national strategies that promote sustainable growth and operational efficiency.

By formulating comprehensive policies and frameworks, the central government establishes the vision and direction for the sector, ensuring alignment with broader national priorities such as enhancing food security, reducing post-harvest losses, and mitigating environmental impacts. Primarily, through ministries such as the Ministry of Agriculture and Farmers' Welfare and the Ministry of Food Processing Industries, the central government coordinates efforts to develop robust infrastructure, incentivise the adoption of energy-efficient technologies and facilitate collaboration among key stakeholders.

Table 5 below provides a snapshot of select national-level policies and schemes governing the cold chain sector in India. While these initiatives collectively aim to enhance the cold chain sector's infrastructure and operational capabilities, they may promote energy efficiency and the uptake of renewable energy either directly or indirectly. It is important to note that the degree to which each policy or scheme contributes to energy transition may vary. Specifically, the National Horticulture Board (NHB) and the Mission for Integrated Development of Horticulture (MIDH) schemes place significant emphasis on developing modern infrastructure with provisions for energy-efficient technologies as a prerequisite for subsidy eligibility, along with the addition of renewable energy (solar and biomass) cost norms as well.

Table 5 Select policies and schemes at the national level

Scheme	Scheme type	Nodal entity	Applicability	Key aspects
Cold Storage Scheme– National Horticulture Board (NHB)	Subsidy	MoAFW	Retrofit, expansion and new setup of post-harvest agricultural infrastructure.	Cold storage infrastructure with capacity between 5000MT to 20000MT is eligible to avail of this subsidy. There is no involvement of the state governments in this scheme.
Mission for Development of Horticulture (MIDH)	Subsidy	MoAFW and state horticulture departments	Retrofit, expansion and new setup of post-harvest agricultural infrastructure.	Cold storage infrastructure with capacity up to 5000MT is eligible to avail of this scheme. This scheme involves central and state governments. National Horticulture Mission (NHM) and State Horticulture Mission (SHM) contribute to this scheme in the ratio of 60:40.
Agriculture Infrastructure Fund (AIF)	Loan	MoAFW	New setup of agriculture related infrastructure, which also covers the cold chain sector.	Medium–long term debt financing for post-harvest management projects. Interest subvention of 3% up to seven years. Loans are provided up to a limit of INR 2 crore. Each applicant may undertake up to 25 projects, with a limit of INR 2 crore per project.

Scheme	Scheme type	Nodal entity	Applicability	Key aspects
Rural Infrastructure Development Fund (RIDF)	Loan	NABARD	Completion of pending projects related predominantly to agricultural infrastructure.	NABARD sanctions loans to state governments to complete pending rural infrastructure development projects. Agriculture and related sectors remain a key area of focus. Loans are provided to state governments for a period of seven years, with an additional two-year grace period.
Agricultural Marketing Infrastructure (AMI) – A sub scheme of the Integrated Scheme for Agricultural Marketing (ISAM)	Subsidy	MoAFW	New setup and retrofit of cold chain infrastructure, warehouses and grading facilities to enhance agricultural marketing.	The scheme focuses on developing and upgrading infrastructure such as cold storage, warehouses and grading facilities to enhance agricultural marketing. It provides financial assistance to both private and public sectors. The aim is to reduce post-harvest losses and improve farmers' market access.
Integrated Cold Chain and Value Addition Scheme under Pradhan Mantri Kisan Sampada Yojana (PMKSY)	Subsidy	MoFPI	New setup as well as modernisation of cold chain infrastructure	Aims to reduce post-harvest losses and enhance the value of perishable agricultural products by providing financial support for cold storage, processing units and refrigerated transport. It focuses on improving the income of farmers by strengthening cold chain infrastructure and creating market linkages for better product quality and shelf life.
Operation Greens under PMKSY	Subsidy	MoFPI	Funding is provided for infrastructure like cold storage, refrigerated transport and processing units. The scheme supports both new setups as well as modernisation of existing infrastructure	Aims to stabilise the prices and reduce wastage of tomato, onion and potato (TOP) by providing financial support for cold storage, processing and transportation infrastructure. It also focuses on improving export competitiveness and creating direct market linkages for farmers, enhancing their income and reducing post-harvest losses.
Rashtriya Krishi Vikas Yojana (RKVY)	Subsidy	Department of Agriculture and Co-operation, MoAFW	New setup of agriculture-related infrastructure, including agribusiness incubators.	Key focus is on enhancing farm productivity, improving infrastructure and increasing farmers' income. The scheme is designed to encourage innovation, technology adoption and sustainable farming practices.

Under the broad initiative of developing a sustainable cold chain sector in India, the NCCD launched the first version of the ‘Guidelines and Minimum System Standards for Implementation in Cold-chain Components’ in 2015. The document outlines the strategic framework for developing a national cold chain network that supports the livelihood of farmers by enabling them to reach distant markets and diversified buyers. It emphasises the importance of technological interventions to expand rural sales footprints, promoting gainful production and sustainable development. It aims to assist individual entrepreneurs in selecting state-oriented infrastructure components. It also provides data sheets for informed project proposals and clarifies the purpose of cost norms, focusing on incentivising investment in key areas in line with government policy directions.

Over the preceding decade, there were significant advancements in technology, shifts in market demands, and changes in agricultural practices, all of which necessitated updates to ensure that the guidelines remained relevant and effective. With this aim, the NCCD launched the revised guidelines in 2025, incorporating modern technological developments and aligning with current market dynamics to further enhance the potential of India’s cold chain sector.

Box 1 below highlights the measures incorporated by NCCD in the revised guidelines related to energy transition, which is the primary focus of this report.

Role of state governments

In addition to the central government, the state governments also play a crucial role in the cold chain policy landscape by implementing localised initiatives that cater to regional agricultural needs and priorities. State governments are involved in statutory approvals for establishing cold chain projects, providing land and facilitating the implementation of schemes. Several states have undertaken significant initiatives to enhance their

cold chain capabilities through state-developed schemes. While not all these schemes are directly related to the cold chain sector, they provide benefits to the sector in various ways. Table 6 below provides a snapshot of some of the key state-level policies in India. The states covered in the table are some of the key agricultural states in India, having a high concentration of cold chain infrastructure as well.



Table 6: Select policies, schemes and/or action plans at state level

State	Scheme	Nodal entity	Applicability	Key aspects
Uttar Pradesh	Uttar Pradesh Food Processing Policy	Dept of Horticulture and Food Processing	New setup, retrofit/modernisation of infrastructure catering to food processing	The policy aims to boost agricultural produce processing and promote exports. It thereby enhances the demand for and development of cold storage facilities in the state. This policy primarily focuses on export-oriented cold storage facilities and food processing units.
	Uttar Pradesh Warehousing and Logistics Policy	Dept of Infrastructure and Industrial Department	Only applicable to facilities which facilitate logistics like reefers, cold chain warehouses, and infrastructure catering to cargo terminals, ports, etc.	Aims to enhance the logistics sector by promoting private investments, developing robust infrastructure, and integrating modern technologies. It focuses on expanding cold storage facilities, offering incentives for logistics projects, and improving connectivity through multi-modal transport networks to boost economic activities and export capabilities in the state.
Maharashtra	Maharashtra Agrobusiness Network (MAGNET)	ADB and Maharashtra State Govt	All components of the value chain for the selected perishables. Both new setup as well as modernisation are covered under this policy	Aims to enhance farmers' incomes by improving post-harvest marketing and value chains for select horticulture crops. It focuses on strengthening institutional and financial capacities of farmer producer organisations, improving agriculture value chain infrastructure, and promoting energy-efficient and renewable technologies for sustainable cold chain operations.
	Agriculture Export Policy of Maharashtra	Maharashtra State Govt	This policy is applicable to all infrastructure related to post-harvest management, agro processing, infrastructure at seaports, airports, etc. Both new setup as well as modernisation are covered under this policy	Aims to establish Maharashtra as an agricultural export hub by promoting export-oriented production, enhancing infrastructure and supporting value-added and organic products. It focuses on cluster development, skill enhancement, and institutional mechanisms to boost exports and improve farmers' income through better market access and policy reforms.

State	Scheme	Nodal entity	Applicability	Key aspects
Karnataka	Karnataka Agribusiness and Food Processing Policy	Karnataka State Agricultural Produce Processing and Export Corporation Limited (KAPPEC)	Applicable to various components of the cold chain, including warehousing, silos, cold storage logistics related to agribusiness, export, processing, handling, and storage of agricultural, horticultural, floriculture, spices, medicinal and aromatic plants, fish, meat, poultry, dairy, and organic produce.	The policy aims to transform the state's agrarian economy by enhancing the agribusiness and food processing sectors. It targets increased processing rates and reduced wastage. The policy emphasises infrastructure development, technology adoption, and the creation of employment opportunities, leveraging Karnataka's biodiversity and resources. It encourages investment, supports FPOs and promotes modern practices to boost agriculture, horticulture and fisheries. The policy aims for sustainable sector growth and improved farm returns.
Tamil Nadu	Tamil Nadu State Agricultural Infrastructure Development Programme	Dept. of Agriculture and Farmers Welfare	All types of cold chain components facilitating logistics.	Infrastructure developments in agriculture are proposed under three key initiatives, productivity improvement, assurance of year-round irrigation and marketing extension. Cold chain logistics is a key component of the strategic plan.
Gujarat	Gujarat Agrobusiness Policy (2016-21)	Agriculture, Farmers Welfare and Co-operation Dept.	This policy is applicable to cold storage facilities, reefer transport, packaging facilities, ripening chambers, logistics, and distribution.	The policy aims to promote the agro and food processing industry in the state to make it more vibrant and sustainable. Cold chain infrastructure, including cold storage (CA), packhouses and reefer vehicles are key components covered under the policy.
Rajasthan	Rajasthan Agri-Business Processing Policy 2019	Dept. of Agriculture	The policy is applicable to cold storages, reefer vans, food irradiation processing plants, packhouses, agro-processing clusters or parks declared by the state government. The policy is applicable to both new agro-processing and agri-business enterprises set up in the state and to existing enterprises undergoing modernisation, expansion, or diversification	The policy aims to promote the export of agricultural products from Rajasthan. Cold storages, packhouses, and export facilitation centres and aggregation centres are covered.

State	Scheme	Nodal entity	Applicability	Key aspects
Punjab	Punjab State Agricultural Policy	Dept. of Agriculture	The policy is applicable to several components including integrated packhouses, solar-supported cold-chain facilities, solar-grid supported cold chain with pre-cooling and ripening chambers, reefer transport facilities, cold storage facilities at Pear Estate Amritsar and for individual farmers, cold chain support for litchi, cold chain facilities for maize processing, and cold chain linkage facilities for transportation of perishables. This policy is applicable to both, new setup as well as modernisation.	The policy is designed to address the challenges of climate change and environmental pollution within the agricultural sector, with the objective of fostering a cleaner and more sustainable Punjab. The policy promotes solar-aided cold storage facilities.
Andhra Pradesh	Andhra Food Processing Policy	Dept of Industries and Commerce	This policy is applicable to several components, including cold storage facilities, refrigerated transportation, packhouses at strategic locations, particularly near high-production clusters. The policy is designed to support both the establishment of new infrastructure and the modernisation of existing facilities.	The policy aims to transform the state into a leading food processing hub by enhancing infrastructure, promoting innovation, and fostering sustainability, thereby boosting economic growth and employment.

Notes:

- The above table is not exhaustive. It tries to capture only the key policies in the states having high agricultural output and a dense concentration of cold chain infrastructure.

3.4. Technologies in the cold chain sector

Technology plays a crucial role in the sustainable development of the cold chain sector in India. Currently, the cold chain sector is viewed as an energy guzzler within India's energy landscape. Advancements in refrigeration technologies, renewable energy integration and smart logistics are pivotal in transforming the cold chain sector into a more sustainable component of India's agricultural supply chain. Stakeholders in the

technology landscape have been focusing on technological advancements, like energy efficiency, renewable energy integration, implementation of sustainable practices and waste management. The government is promoting private sector involvement and infrastructure development. Table 7 below illustrates the cooling techniques currently employed in the cold chain sector in the country along with the application.

Table 7: Indicative list of cooling technologies and its application

Cooling principle	Penetration in India	Cooling Temp. range	Application in cold chain links	Suitability	Operating efficiency	Refrigerant use	Scale
Vapor compression	More than 90%	-18 to 20 Deg. C	Entire cold chain	All climatic conditions	Electric (IKW/TR)	HFC/HFO, CO ₂ , NH ₃	Small-large scale
Sorption	Less than 5%	-18 to 20 Deg. C	Entire cold chain except transport	All climatic conditions – in presence of heat source	Thermal	Natural refrigerant	Medium-large scale
Evaporative	Less than 5%	Above 15 Deg. C	Bulk storage	Dry and low humid ambient	-	Water	Small-medium scale

From the purview of this report, the technological landscape was assessed based on five parameters, as mentioned below in Table 8.

Table 8: Description of key assessment parameters

Key parameter	Description
Refrigeration system	This category encompasses the equipment and technology used to maintain low temperatures essential for preserving perishable goods during storage and transport. A typical refrigeration system consists of key components such as evaporators, condensers, compressors and the respective ancillary equipment, all working together to ensure efficient heat exchange and cooling.
Refrigerant	Refrigerants are the chemical substances used within refrigeration systems to absorb and release heat, facilitating the cooling process. Refrigerant use affects the system efficiency as well as the environment.
Insulation	Insulation materials are critical in maintaining the desired temperature range within cold storage facilities and transport vehicles. Effective insulation reduces heat transfer, thus enhancing energy efficiency and ensuring temperature uniformity.

Key parameter	Description
Operations and management (O&M)	O&M refers to the practices adopted to ensure the optimal performance and longevity of cold chain systems.
Digitisation	This involves the use of IoT sensors, RFID and automation to monitor temperature, track inventory and optimise operations in real time. This enhances efficiency and reduces spoilage.

3.5. Government support on financing of cold chain infrastructure

Financing mechanisms for India's cold chain are diverse, encompassing government subsidies, loans, private investments, PPPs, blended finance and international funding. These mechanisms, supported by tax incentives and growing market opportunities, can drive the sector towards sustainability, aligning with India's net-zero commitments and enhancing food security.

- **Loans and credit facilities:** Financial institutions play a vital role in providing credit for cold chain projects. Priority Sector Lending norms by the Reserve Bank of India cover loans for cold storage units, and the Agricultural Infrastructure Fund, with a fund size of INR 100,000cr, offers collateral-free loans with 3% interest subvention (Agarwal, 2023). Additionally, NABARD has set up a special fund of INR 2,000cr for credit at affordable rates to boost the food processing sector, including cold chain infrastructure.
- **Private investments and public private partnerships:** Private investment is a major driver, with 95% of cold storage capacity owned by the private sector (Mordor Intelligence, 2025). The sector has attracted FDI worth INR 500 billion in the last nine years, indicating strong investor confidence. Public-Private Partnerships (PPPs) are revolutionising the sector, reducing post-harvest losses and attracting significant investments for modern cold storage and transport networks (ICAR, 2007). Recent reports highlight investments under PMKSY, with 41 Mega Food Parks and 353 cold chain projects approved, leveraging private sector expertise.

- **Blended finance and international funding:** Blended finance, combining public and private capital, is emerging as a potential mechanism, though its application in India's cold chain is still developing. Examples from other regions, such as Morocco's cold storage project at Port of Tanger Med, with a USD 11 million investment using blended finance (Lixcap.com), suggest applicability. The World Bank's report, 'Climate Investment Opportunities in India's Cooling Sector', highlights a USD 1.6 trillion opportunity by 2040, with cold chains reducing food loss by 76% and carbon emissions by 16%, supported by concessional finance from multilateral development banks (WorldBank, 2022).
- **Tax incentives and other mechanisms:** Tax incentives further reduce financial burdens, with Section 80-IB of the Income Tax Act offering 100% profit deductions for the first five years and 25–30% for the next five years for cold chain-related industrial activity. Customs duty is concessional at 5% for cold storage and fully exempted for reefer vehicles, while excise duty is fully exempted for cold storage equipment (pManifold, 2023).

Challenges include high initial costs for renewable energy technologies, limited access to finance for small farmers and the need for technical expertise. Opportunities lie in the growing market demand, with projections reaching INR 5.09 trillion by 2029 at a CAGR of 16.43%, and government support through schemes and incentives, potentially attracting more private and international investment.

Observation

- India's post-harvest cold chain is heavily skewed toward single commodity bulk storages, with roughly 75% of the capacity dedicated to potatoes.
- Farm gate infrastructure (standard/integrated packhouses, pre cooling, on farm cold rooms) remains sparse in Uttar Pradesh, West Bengal, and Gujarat; Maharashtra and Andhra Pradesh show better presence at the first mile.
- Multi commodity cold storages are fewer and largely concentrated in Maharashtra and select tier 1 locations; ripening infrastructure is focused primarily on bananas, with limited diversification to other potential crops.
- Reefer vehicles exist but are clustered on major corridors and in tier 1 markets, used mainly by organized players and export oriented flows; utilization is uneven elsewhere.
- Supply chains are fragmented, requiring stronger multi agency coordination to improve end to end integration.
- High upfront costs for renewable/hybrid solutions persist; older potato bulk storages (generally >10–15 years) remain highly energy intensive.
- Small farmers and FPOs face constrained.
- Access to affordable finance, alongside skills gaps in operations, maintenance, and digitization.
- Awareness of energy efficiency measures and disciplined O&M practices among facility owners.

¹<https://www.mordorintelligence.com/industry-reports/india-cold-chain-logistics-market>

²<https://www.lixcap.com/en/blended-finance-investment-development-for-the-cold-chain/>



4. Overview of the Global Cold Chain Trends

The global cold chain sector is undergoing rapid transformation, driven by technological advancements, sustainability imperatives and evolving market demands. Below are the key

trends shaping the cold chain sector, with a focus on their relevance to energy transition strategies for the cold chain sector in India.

4.1. Sustainability and energy efficiency

The cold chain industry is energy-intensive, and there is a strong push toward sustainable practices to reduce carbon footprints while maintaining efficiency. Key developments include:

- **Adoption of renewable energy:** Cold chain facilities are increasingly integrating renewable energy sources, such as solar and wind, for on-site power generation to reduce reliance on fossil fuels. For example, solar-powered cold storage units are being deployed to enhance energy efficiency.
- **Energy-efficient refrigeration technologies:** The 'Move to -15°C coalition' and other initiatives promote the use of sustainable refrigerants and energy-efficient refrigeration systems to lower greenhouse gas emissions.
- **Infrastructure modernisation:** Ageing cold chain infrastructure is being phased out in favour of modern, energy-efficient warehouses and transportation systems to meet stricter environmental regulations and market demands.

4.2. Technological innovation and digitalisation

Advanced technologies are transforming cold chain operations by improving visibility, efficiency and resilience:

- **Internet of Things (IoT) and AI integration:** IoT-enabled sensors and AI-driven analytics are being used for real-time temperature monitoring, predictive maintenance and supply chain optimisation. Embedded sensor technology addresses blind spots in logistics, ensuring product integrity.
- **Blockchain and data analytics:** Blockchain is increasingly adopted for traceability and transparency, particularly in pharmaceutical and food supply chains, to ensure compliance and reduce losses.
- **Automation:** Larger facilities are incorporating automation for sorting, packing and inventory management to enhance efficiency and reduce energy consumption.

4.3. Resilience against geopolitics and environmental challenges

Geopolitical disruptions and climate change are prompting cold chain operators to build more resilient supply chains:

- **Geopolitical adaptability:** Recent geopolitical unrest has impacted transit times and capacity, pushing operators to diversify supply chains and invest in strategic stock management to mitigate risks.
- **Climate resilience:** Extreme weather events, such as floods and droughts, necessitate adaptive logistics systems and resilient infrastructure to ensure uninterrupted cold chain operations.
- **Built-to-Suit facilities:** Customised cold storage facilities near production or import hubs are being developed to enhance trade efficiency and reduce energy waste.

4.4. Consolidation and strategic partnerships

The cold chain industry is witnessing consolidation through acquisitions and partnerships to enhance supply chain integration and resilience:

- **Mergers and acquisitions:** In markets like North America and Europe, private equity firms are acquiring cold storage companies

to consolidate operations and improve economies of scale.

- **Logistics partnerships:** Businesses are partnering with logistics providers to gain better visibility and integrate supply chains, particularly for pharmaceuticals and fast-moving consumer goods (FMCG).

4.5. Circular economy practices

The cold chain industry is embracing circular economy principles to minimise waste and optimise resource use, aligning with sustainability goals.

- **Reusable packaging solutions:** Cold chain operators are adopting reusable, insulated packaging materials for temperature-sensitive goods, reducing single-use plastics and lowering environmental impact. For

instance, phase-change material (PCM) packaging is gaining traction for maintaining temperatures during transport.

- **Recycling and upcycling infrastructure:** Facilities are integrating recycling systems for refrigerants, packaging and equipment, while some are upcycling old refrigeration units into energy-efficient systems to extend their lifecycle.

4.6. Consumer-driven demand for transparency

Growing consumer awareness of sustainability and product safety is driving demand for greater transparency in cold chain operations.

- **End-to-end traceability:** Consumers, especially in food and pharmaceutical sectors, are demanding detailed information on product origins, storage conditions, and carbon footprints, prompting operators to

adopt QR code-based tracking and consumer-facing apps.

- **Sustainability reporting:** Cold chain companies are publishing detailed sustainability reports to showcase energy-efficient practices and low-carbon operations, building trust with environmentally conscious consumers.

4.7. Refrigerant transition

Refrigerants are significant components of the cold chain sector. They ensure that temperature-sensitive goods are handled safely from farm to consumer. However, many legacy refrigerants have high global warming potential (GWP) and/or ozone depletion potential (ODP), making refrigerant transition central to a sustainable, low-carbon cold chain.

Globally, the cold chain has transitioned through several generations of refrigerants. Chlorofluorocarbons (CFCs) have been largely phased out due to their ozone-depleting nature, replaced by hydrochlorofluorocarbons (HCFCs) and

then hydrofluorocarbons (HFCs). While HFCs have lower ODP, many (like R-134a, R-404A) have very high GWP. Large cold storages often use ammonia (R717), prized for energy efficiency and near-zero GWP, though it is toxic and flammable. Carbon dioxide (CO₂, R744) and hydrocarbons (propane – R290, isobutane – R600a) are increasingly utilised as natural, low-GWP options for both large and small cold chain systems internationally.

Table 9 summarises the global trends with respect to predominant refrigerants component wise and future trends.

Table 9 Trends in refrigerant transition globally

Cold Chain Component	Historical (2015)	Current/Future (2025)	Key Trends
Pack Houses	HCFC R-22, HFC-R134a, R404A	CO ₂ , NH ₃ (where allowed), HFO blends, R290	Strict GWP limits via EU F-gas/AIM Act; rapid HFC phase-down; shift to natural/low-GWP refrigerants
Bulk Cold Storages	NH ₃ (ammonia), HCFC R-22	NH ₃ (still dominant), CO ₂ , HFO blends (R448A, R449A, R452A)	Ammonia remains standard for large storage in US, EU; growing CO ₂ usage due to safety and environmental regulations
Ripening Chambers	HCFC R-22, HFC-R134a, R404A	R290 (propane), HFOs, CO ₂	Preference for hydrocarbons/low-GWP options; new builds rarely use legacy HFCs
Reefers	HFC-R134a, R404A	R452A, R513A, R1234yf, CO ₂	Reefers: GWP<150-700 now required for new equipment; legacy phased out rapidly under EU/US rules

Key regulatory frameworks drive the transition from high-GWP refrigerants to more environmentally friendly alternatives in these major countries. Here's a brief overview of the main regulatory drivers in each region:

EU: F-Gas Regulation

- **Objective:** The regulation primarily aims to reduce emissions of fluorinated greenhouse gases, including HFCs, which are used in refrigeration, air conditioning and other applications.
- **High-GWP refrigerants ban:** It specifically

targets the use of high Global Warming Potential (GWP) refrigerants in new equipment, encouraging a shift towards more environmentally friendly alternatives.

- **HFC phase-out:** The regulation sets a timeline for gradually phasing out HFCs, which are known for their high GWP, and replacing them with natural or low-GWP alternatives, such as carbon dioxide or ammonia.
- **Alternatives mandate:** Manufacturers are incentivised to adopt natural refrigerants or those with low GWP to comply with the regulation, fostering innovation and the development of sustainable technologies.

US: American Innovation and Manufacturing (AIM) Act

- **Objective:** The American Innovation and Manufacturing (AIM) Act is a federal law designed to phase down the production and consumption of HFCs, aligning with international agreements like the Kigali Amendment to the Montreal Protocol.
- **HFC phasedown:** The AIM Act sets a schedule for reducing the use of HFCs, aiming for an 85% reduction by 2036 through a series of steps, decreasing environmental impact.
- **GWP caps in transport:** The Act contains

provisions to establish GWP limits for refrigerants used in transportation sectors, such as automotive air conditioning and the cold chain sector, thereby promoting the adoption of cleaner technologies.

- **Tax incentives:** It also incorporates tax incentives to encourage the development and use of low-emission technologies, thereby supporting industries to transition to environmentally friendly solutions.

EU and US are far ahead in phasing out high-GWP HFCs, driven by stringent regulation, with most new facilities adopting natural or HFO refrigerants.

4.8. Relevance to India's energy transition strategies

The abovementioned trends are highly relevant to India, where the cold chain sector is critical for agriculture, pharmaceuticals and food security. The adoption of renewable energy, low-GWP refrigerants and energy-efficient technologies aligns with India's National Cooling Action Plan and commitments under the Paris Agreement. Technological advancements like IoT, AI and blockchain can address India's challenges with

fragmented supply chains and high post-harvest losses. Resilience strategies, including regionalised supply chains and disaster-ready infrastructure, are vital because India is vulnerable to climate change and geopolitical trade disruptions. Finally, PPPs and global network expansion can accelerate India's cold chain infrastructure development. These measures support energy transition goals while boosting economic growth.

Observation - global landscape

- The global cold chain is rapidly modernizing, driven by sustainability and technology, as operators cut energy use and emissions through renewable integration, high efficiency refrigeration, and facility upgrades.

Digital transformation

- IoT based real time monitoring, AI driven analytics, blockchain traceability, and targeted automation—is boosting end to end visibility, reliability, and efficiency across storage and transport. In parallel, resilience measures—route diversification, climate adapted logistics, and built to suit capacity near production/import hubs—are mitigating climate risk and strengthening service continuity.

Circular Practice

- Practices such as reusable insulated packaging, PCM solutions, and refrigerant/equipment recovery are reducing waste, driven by expectations for full traceability and sustainability reporting.
- A central shift is the refrigerant transition away from high-GWP HFCs toward natural and low-GWP .
- options, accelerated by stringent EU (F-Gas regulation) and US (AIM Act) regulations.



5. Perishables Landscape in India

5.1. National-level perishables landscape

India's production of fruits and vegetables has reached 282 million tonnes from 16.77 million hectares over the past decade and exhibits a 1.2% annual growth rate (DoA&FW, 2023). While ICAR-CIPHET estimates fruit and vegetable losses at 3.5% of the total agricultural gross value added (GVA) and 1.52% specifically for fruits. Several scholars and government agencies contest these figures. A more realistic estimate, based on FAO data, suggests losses amount to 3.5% of GVA from fruits and vegetables alone.

This study investigates the energy efficiency of cold chains for perishable goods in India. To ensure a comprehensive assessment, the study team implemented a rigorous selection process, utilising seven key criteria based on consultations with industry experts. These criteria are as follows:

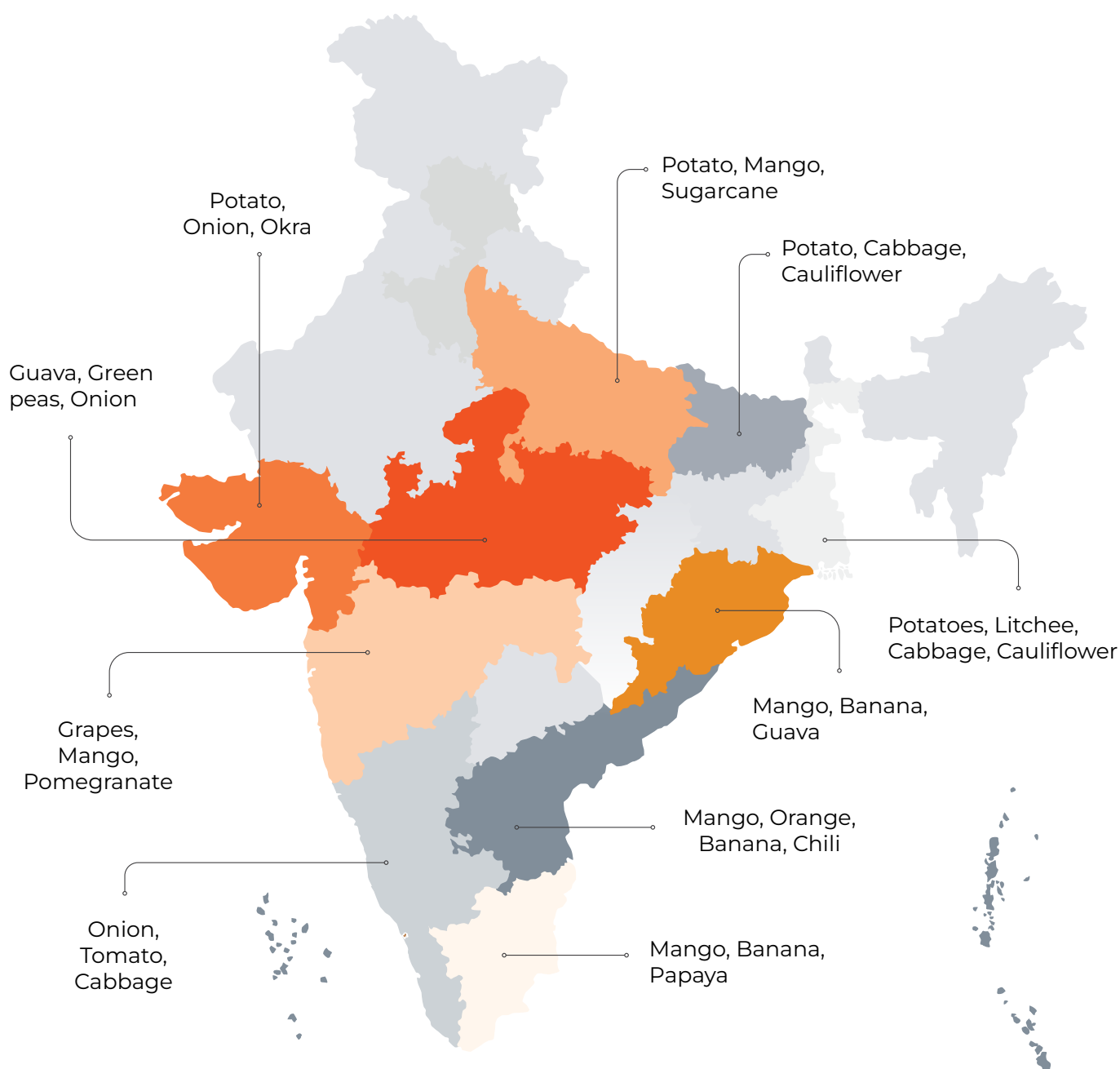
- **Production volume:** Reflecting the scale and national significance of each commodity, production volume highlights the extent of agricultural output and its contribution to the food system across India.
- **Production value:** This criterion determines the economic contribution and market size of each commodity, offering a perspective on its relevance to national and regional economies.
- **Value per tonne:** Providing insights into economic efficiency, this measure helps assess price volatility and potential profitability, influencing strategic resource allocation in the cold chain development.
- **Wastage percentage from production:** Highlighting potential inefficiencies within the existing cold chain infrastructure, wastage percentage points to areas where improvements in technology and infrastructure could significantly reduce losses.
- **Projected future demand:** Informing strategic planning for infrastructure development, future demand estimates help forecast the growth trajectory and necessary enhancements in cold chain capacity.

- **Export value:** Underscoring the role of international trade, export value indicates commodities' significance in global markets, emphasising the importance of maintaining high standards of safety and quality.
- **Shelf life:** Guiding the development of tailored storage and transportation solutions, shelf-life considerations allow for precise temperature and humidity control requirements, critical to maintaining product integrity.

By applying these criteria to select key perishables, this study aims to deliver valuable insights into energy efficiency within the cold chain, supporting informed decision-making and promoting sustainable practices for a more resilient and efficient food system.

Moreover, it is vital to recognise that food loss and waste are dynamic concepts. They may increase as rising incomes drive consumer demand for food with higher safety and hygiene standards. Losses are most significant in vegetables, followed by fruits and staple crops. It is crucial to prioritise loss reduction strategies for vegetables such as potato, onion, tomato, cabbage, green peas, and cauliflower in regions such as Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Uttar Pradesh, and West Bengal. Similarly, it is essential to reduce losses in fruits such as mangoes, grapes, apples, guava, and papaya from Andhra Pradesh, Bihar, Jammu and Kashmir, Madhya Pradesh, Maharashtra and Uttar Pradesh (Institute of Economic Growth, August 2021).

Figure 8 below presents an overview of the top perishable produce across the top 10 states in India, in terms of the horticulture production volume.

Figure 8: Perishables mapping across top states in India

India is the second-largest producer (Food Laws & Regulations in Fruits & Vegetable Sector, 2019) of fruits and vegetables in the world. This makes horticulture a significant contributor to India's economy, contributing approximately 33% to India's agricultural GDP (Ministry of Agriculture & Farmers Welfare, 2023). Table 10 shows the top 10

states in India in terms of the volume of horticulture production. The highest number of agricultural post-harvest cold chain infrastructure is mostly found only in these states. These top 10 states account for nearly 80% of the total horticulture production in India.

Table 10: Top ten states with horticulture production in India

Rank	State	Horticulture production (2021-22) in lakh MT	% share in India's total production
1	Uttar Pradesh	440.95	~13%
2	Madhya Pradesh	353.14	~10%
3	West Bengal	332.07	~10%
4	Maharashtra	307.74	~9%
5	Gujarat	262.43	~8%
6	Andhra	259.99	~7%
7	Bihar	229.58	~7%
8	Karnataka	220.53	~6%
9	Tamil Nadu	208.50	~6%
10	Odisha	129.49	~4%

Table 11 provides a concise assessment of ten major perishable commodities produced in India, detailing their optimal storage conditions and shelf life without the use of a cold chain. The table outlines the specific temperature and relative humidity (RH) requirements necessary to

maintain the freshness of each perishable item. Subsequently, three perishables from this list have been selected for a detailed assessment of their respective value chains, aiming to identify potential opportunities for energy transition.

Table 11 Assessment of ten major produced perishables in India

Selected perishable	Temperature and RH requirement	Shelf life without introduction to cold chain	Season of harvest	Source
Potato	For table potatoes: Temp: 1 to 2.2 °C RH: 90-95% For CIPC treated potatoes: Temp: 7.7 °C to 8.8 °C RH: 90-95%	7-15 days	Dec-Mar	(Rinac, 2022) (Rees, 2021) (Camelo, 2004) (Shikhamany, 2000) (MINISTRY OF AGRICULTURE, 2009)
Grapes	Temp: -1 to 1 °C RH: 85 - 90%	Up to 2 days	Dec - Apr	(TNAU, Agricultural Marketing Information System (AMIS), 2014) (Bangalore, 2023) (Tourism, 2023)
Pomegranates	Temp: 4 to 6 °C (2-3 months of storage) 10 °C (longer duration) RH: 90-95%	1 – 2 weeks	Maharashtra and Gujarat – year round Karnataka – January to April Andhra – March to June	(Marco, 2021) (Ecofrost, 2019)

³https://www.dsir.gov.in/sites/default/files/2019-10/AF_Farm_Fruits_Vegetables_Intro_0.pdf

Selected perishable	Temperature and RH requirement	Shelf life without introduction to cold chain	Season of harvest	Source
Green peas	Temp: 0 °C RH: 95-98%	Around 2 weeks	Oct – Nov for sowing and harvesting 75 days after sowing	(Rinac, 2022) (TNAU, 2022)
Mango	Temp: 11 to 18 °C depending on the mango type RH: 85-90%	4 – 8 days	Mar - July	(TNAU, Agricultural Marketing Information System (AMIS), 2014) (NHB, n.d.) (P.P. Lei Yi, 2019)
Chilli	Temp: 8 to 12 °C RH: around 95%	2 – 3 weeks	Depends on the region. South India -Year – round North India – Winter season	(BluecoldRefrigeration, 2021) (Map-India, 2024)
Tomato	Temp: 13 to 16 °C RH: 85-90%	1 – 2 weeks	Year – round	(Dahiya, 2023) (NHB, 2019)
Avocado	Temp: 7 to 13 °C RH: 85-90%	2 – 4 weeks	Sikkim – July to October Tamil Nadu – July to August	(TNAU, Agricultural Marketing Information System (AMIS), 2014) (Ghosh, n.d.) (Semcold, n.d.)
Banana	Temp: 13 to 14 °C RH: 90-95%	3 – 5 days – unripe The shelf life shortens further as they ripen	September to April	(NHB, Banana Post Harvest Technology) (Jadhav, 2018)
Apples	Temp: -1 to 3 °C RH: 90-98%	5 – 7 days	Sep – Oct	(TNAU, Agricultural Marketing Information System (AMIS), 2014) (NHB, n.d.) (Rinac, 2022)

5.2. Selection of the states and perishables for the assessment

The study identified three perishables in India by considering these selection parameters as mentioned in section 6.1. In addition to the seven national-level criteria, the selection of these specific perishables for state-level assessment considered two crucial factors: 1) Responsiveness of state authorities: The

study prioritised states demonstrating a proactive approach and willingness to collaborate, ensuring efficient data collection and implementation of potential recommendations. 2) Stakeholder availability and willingness.

Furthermore, the study used the geographic location of production, distribution and consumption as qualitative indicators to identify the three perishables.

Table 12 below captures the list of perishables and states that were assessed as a part of this study for the evaluation of cold chain infrastructure.

Table 12 Selection of three perishables for the study

Perishable	States	Economic impact	Cold chain dependency	Type of Cold chain infrastructure covered
Potato	Uttar Pradesh, West Bengal and Gujarat	As the largest produced horticulture crop in India, potatoes significantly impact the agricultural economy due to their high production volume. Potato production generated INR 513 billion in value in 2021. While traditionally a staple for domestic consumption, there is a growing interest in expanding the export market for potatoes, which presents new opportunities for economic growth and diversification of India's agricultural exports.	The extensive reliance on cold storage facilities for potato preservation highlights the critical role these infrastructures play in maintaining food security and operational efficiency. Type 1 facilities cater to the storage of potatoes.	Type 1 cold storage facilities, export-oriented packhouses, and reefers for export-oriented vehicles
Grapes	Maharashtra	Grapes are a high-value crop with a strong export orientation, contributing substantially to India's agricultural exports. In 2023-24, India exported 3.43 lakh MT of grapes, corresponding to a value of USD 417 million (APEDA, n.d.). They have established markets in Europe and the Middle East, and their economic value is further enhanced by the potential for value addition through products like wine and raisins. Focusing on grapes can provide insights into enhancing export strategies and expanding market reach, thereby boosting the agricultural sector's global competitiveness.	The need for advanced cold chain solutions to maintain quality during transportation is crucial for grapes, especially given the international standards required for export markets. Type 2 facilities cater to the storage of grapes.	Type 2 facilities, FPO cold chain infrastructure, APEDA-registered integrated packhouses, and Type 4 facilities. Ripening units– Type 3 facilities (only applicable to banana and mango ripening)

Perishable	States	Economic impact	Cold chain dependency	Type of Cold chain infrastructure covered
Chillies	Andhra Pradesh	Chilli is a mid-value crop with a lot of potential for export, either in the raw form or processed form. Indian chilli has an established export market in the subcontinent as well as the Middle East. Chillies have been introduced to the cold storage facilities in the recent years, owing to the rising demand and decent yield to farmers.	Chilli has gradually increased its dependency on cold storage infrastructure. Type 4 facilities cater to the storage of chillies. Apart from Type 4 facilities, chilli is also a crucial perishable for food processing units, as chilli powder is another major export-oriented product.	Type 4 facilities, FPO cold chain infrastructure, and APEDA-registered integrated packhouses. Ripening units– Type 3 (only applicable to banana)

The selection considered the accessibility and participation of key stakeholders within the potato, chilli, and grape value chains, facilitating comprehensive field assessments and data gathering. By focusing on these three perishables and incorporating stakeholder engagement, the

state-level assessment aims to provide targeted insights and actionable recommendations for enhancing energy efficiency and promoting sustainable practices within India's cold chain infrastructure.

5.3. Overall perishable assessment in the states

The selected states for the assessment have a rich agricultural output and contribute extensively to the overall agricultural output of the country. Together, these states account for 47% of India's agricultural output. Further to the identified perishables for the assessment, this section delves into the overall perishables landscape for the selected states.

Table 13 (Horticulture Statistics Division, Department of Agriculture & Farmers Welfare, & Ministry of Agriculture & Farmers Welfare, 2021) below outlines the major perishables produced in the selected states for this study.

Table 13 Perishable landscape in the selected states for assessment (2020)

No.	Perishable	State	Production (LMT)	Productivity (MT/Ha)
1	Potato	Gujarat	36.16	30.65
		Uttar Pradesh	130.00	22.81
		West Bengal	125.63	28.88
		India	561.72	25.5
2	Mango	Andhra	45.17	12
		Uttar Pradesh	48.06	17.21
		Gujarat	9.97	6.09
		India	203.85	8.80
3	Grapes	Maharashtra	23.99	20.89
		Telangana	0.11	33.17
		India	33.57	21.62
4	Chilli	Andhra	7.96	4.49
		Maharashtra	0.24	4.37
		Uttar Pradesh	0.12	0.89
		India	20.49	2.89
5	Banana	Andhra	58.34	60
		Gujarat	39.07	65.94
		Maharashtra	42.23	50.12
		India	330.61	35.78

Cold storage landscape of perishables in the selected states

- **Andhra Pradesh:** Chillies are mainly stored in dedicated facilities (classified as Type 4), along with major fruits like mangoes and bananas, which are typically managed in specialised units such as ripening units for bananas and integrated packhouses for mangoes.
- **Gujarat:** Perishables in cold storage facilities include potatoes and bananas. Potatoes are predominantly housed in Type 1 facilities, designed for single-commodity storage, while bananas and mangoes are stored in chambers of Type 2 facilities, offering multi-commodity storage. Data from the Gujarat Chamber of Commerce and Industry (GCCCI) indicates that there are 412 Type 1 cold storage facilities solely dedicated solely to potato storage. These facilities constitute 40% of the state's total cold storage facilities. Gujarat's industrialised nature has resulted in the establishment of numerous food processing and storage units..
- **Maharashtra:** The focus is on the storage and processing of fruits, with a mix of Type 2, 3 and 4 facilities storing a variety of perishables. These include fruits such as grapes, bananas and mangoes, along with spices like chilli and turmeric and lentils. The storage of mangoes is less prevalent during the off-peak season. Maharashtra emphasises food processing, with fruits commonly transformed into value-added products like juices, pulp and cut pieces.
- **Uttar Pradesh and West Bengal:** Similar patterns exist in the storage of perishables, with potatoes dominating storage facilities. West Bengal's cold chain facilities are predominantly Type 1, focusing on potato storage. Uttar Pradesh shows a slightly more diverserange, including spices, lentils, bananas and mangoes. Bananas and mangoes are typically housed in Type 3 facilities designed for multiple fruits, while spices and lentils are managed in Type 4 facilities, tailored for specific processing needs.

5.4. Perishables cold supply chain in the selected states

To understand intricacies of the cold supply chain, it is essential to evaluate the logistical flows, infrastructure and temperature management strategies employed in different regions. This analysis provides insights into how each state manages its cold supply chain operations for

different types of perishables. The following Table 14 details the logistic flows and temperature categories of key perishables in the selected states, highlighting the distinct approaches aimed at optimising the supply chain for both local and export markets.

Table 14 Cold supply chain of the observed perishables

No.	State	Product	Logistics flow	Category (temperature range)
1	Andhra Pradesh	Chilli	CR – Ts – M (FPO model) CS – Ts – M (farmer trader model)	Mild chill (8 – 12 °C)
		Mango	PH – T – S&G – RC (country specific) – CR – GI – T – Me (export model)	Mild chill (8 – 13 °C)
		Banana	Ts – RC – t – M (local consumption)	Mild chill (10 – 13 °C)
2	Gujarat	Mango	PH – T – CH – RC (optional) – t – M	Mild chill (8 – 13 °C)
		Potato	CS – Ts – M (farmer trader model) CS – T – S&G – T – Me (export model)	Chill (0 – 10 °C)
3	Uttar Pradesh	Potato	PH (Agra belt) – CS – Ts – M	Chill (0 – 10 °C)
		Chilli	Ts – CH – t – M (local consumption)	Mild chill (8 – 12 °C)
		Mango	Ts – RC – t – M (local consumption) PH – T – CH – RC (optional) – T – Me	Mild chill (8 – 13 °C)
4	Maharashtra	Grapes	Ts – CH – t – M (local consumption) PH – T – FP – CH – T – Me (export model)	Absolute 0 (0 °C)
		Banana	Ts – RC – t – M (local consumption)	Mild chill (10 – 13 °C)
		Chilli	Ts – CH – t – M (local consumption)	Mild chill (8 – 12 °C)
5	West Bengal	Potato	CS – Ts – M	Chill (0 – 10 °C)

Note:
CH – Cold storage hub, CR – Cold Room, CS: Cold Storage, M – market/consumer end merchandising, Me – Export market, RC – Ripening chamber, t – last mile transport, T – Reefer transport, Ts – non-reefer transport, PH – Pack House, S&G – Sorting and Grading, FP – Food processing facility, GI – Gamma Irradiation

5.5. Landscape of cold chain in Jammu and Kashmir (J&K)

J&K is India's leading apple-growing region and also produces cherries and plums in shorter, high value windows. The crop calendar (apple harvest Aug–Nov; CA release Jan–May; cherries/plums May–July) strongly shapes cold chain usage

Infrastructure stock and growth: The cold chain is anchored by Controlled Atmosphere (CA) cold storages serving apples. Installed CA capacity has roughly tripled since the mid 2010s to about 350,000 metric tonnes across an estimated 70–80 units, with most assets clustered in major apple belts (e.g., Sopore/Baramulla, Shopian, Pulwama). Growth has been catalysed by central and state schemes including MIDH, AIF, PMKSY/SAMPADA, and the Holistic Agriculture Development Plan (HADP). Since 2020, dozens of modern packhouses with grading/packing lines and some pre cooling have been sanctioned/commissioned, improving coverage in apple clusters; such facilities remain more limited for cherries and vegetables. Recently, operators have begun to store plums and cherries opportunistically in existing cold stores, reflecting evolving demand and capacity availability

Transport and logistics: Reefer usage in apples is still limited. Most harvest season movements to mandis occur in ambient trucks; reefers are used more for long hauls and during CA release months when temperature control is critical. High seasonal concentration, cost sensitivity, backhaul challenges, and patchy availability of reefer plug in points deter wider use. For cherries/plums, the short season and fast turnaround requirements underscore the need for rapid pre cooling and reliable temperature controlled transport, which is improving but not yet universal.

In summary, J&K's cold chain has expanded rapidly,—anchored by CA storage for apples and supported by central/state schemes. However, first mile pre cooling, integrated packhouses for cherries/plums, reliable power, and cost effective reefer use remain key constraints. Aligning new investments with NCCD's EG&MSS 2025, accelerating digitization and traceability, and deploying performance linked finance can raise utilization, cut losses and energy intensity, and extend benefits beyond apples to other high value crops.

Observation

- Key focus is on three perishable value chains which are potatoes (Uttar Pradesh, West Bengal, Gujarat), grapes (Maharashtra), and chillies (Andhra Pradesh)
- State snapshots: Uttar Pradesh and West Bengal are heavily potato-centric with predominantly older (> 15 years) single-commodity storages; Gujarat has a large base of Type 1 potato facilities—including export-oriented units—with a mix of old (> 15 years) and newer assets; Maharashtra features a diversified, multi-commodity storage and processing ecosystem; Andhra Pradesh has dedicated chilli storage.
- Ripening and packhouse capacities are majorly seen for mango and banana cold chain.
- Jammu & Kashmir has rapidly expanded controlled-atmosphere (CA) storage for apples—about 350,000 MT across 70–80 units—enabled by central and state schemes.
- Persistent gaps include first-mile pre-cooling and integrated packhouses, unreliable power in remote areas, and limited, uneven use of reefers.



6. Assessment of Selected Perishables Cold Chain in India

6.1. Cold chain assessment of three perishables

The following sections delve deeper into the selected perishables for the assessment of their post-harvest cold chain management. The assessment aims to provide a comprehensive understanding of the current practices, challenges, technological applications, renewable energy uptake and the electricity tariffs within

the cold chain for these selected commodities. By thoroughly analysing the storage, transportation and processing components, this study seeks to identify potential areas for energy optimisation and transition, which could lead to more sustainable and cost-effective cold chain operations across the country.

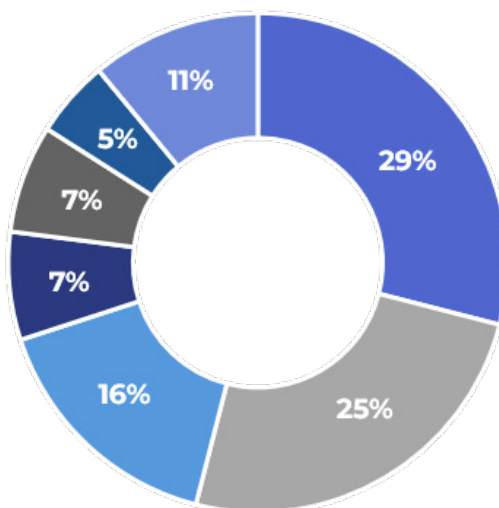
Potato cold chain

Potato cold supply chain dynamics

Potatoes are a cornerstone of the Indian agricultural sector, serving as a staple food source and a high-value horticultural crop. Potato cultivation is the leading crop in India by both production volume and value, and it holds significant economic importance. In 2021, India produced 56.1 million metric tonne of potatoes, generating a production

value of INR 513 billion. Figure 9 below presents the state-wise share of potato production in India. The states of Uttar Pradesh, West Bengal, Bihar, Gujarat, Madhya Pradesh, and Punjab are the major producers of potatoes. In 2020-21, these states accounted for approximately 89% of the total production. (Post-harvest profile of Potato, 2020).

Percentage share of potato production



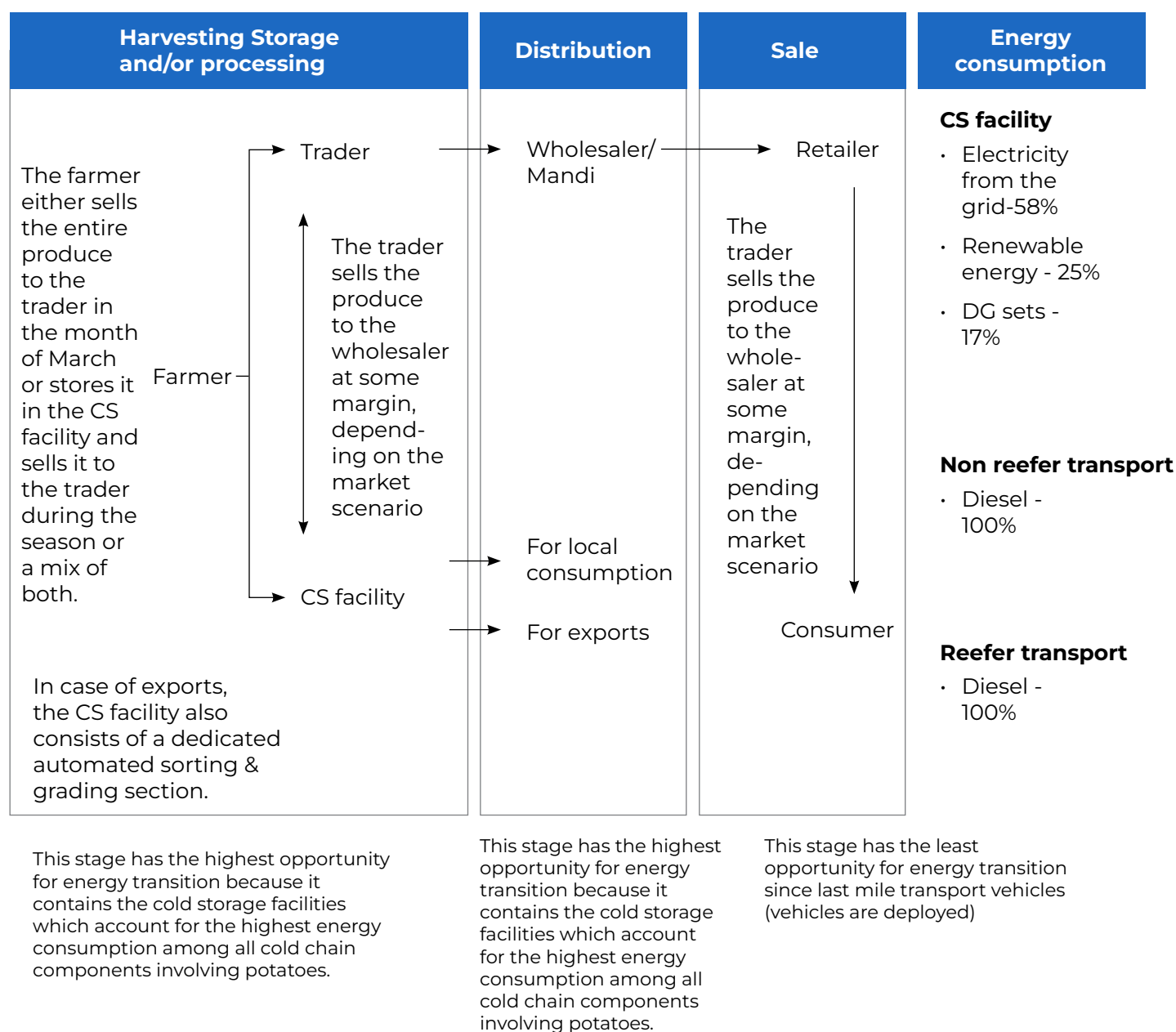
■ Uttar Pradesh ■ West Bengal ■ Bihar ■ Gujarat ■ Madhya Pradesh ■ Punjab ■ Others

Source: Author analysis

Cultivated across diverse agro-climatic zones in nearly every state, potatoes dominate India's cold storage infrastructure. Over 75% of the nation's cold storage capacity is dedicated to potato preservation, primarily in single-commodity facilities that tend to be older than their multi-commodity counterparts. This presents a timely opportunity to evaluate the energy efficiency potential of these facilities and develop a comprehensive energy transition roadmap for India's potato cold chain.

India's potato season extends over nine months, typically from March to November. Cold storage facilities commence potato intake in the second or third week of March, concluding by the first or second week of April across all producing states. A phased unloading of stored potatoes occurs from March to November, aligned with market demand. The period between December and February is reserved for facility shutdown and essential maintenance, ensuring optimal operational readiness for the subsequent loading season. Figure 10 below illustrates a typical potato supply chain observed in India.

Figure 10: A typical potato supply chain in India



Note:
The energy consumption split highlighted in the above figure is based on the calculations done on the collected electricity bills of the visited facilities.

Observations from site visits

The two states considered for the assessment of the potato cold value chain account for more than 60% of the country's total potato production as well as more than 60% of India's cold chain infrastructure. The following sections provide summary of key observations from site visits.

Potato cold chain infrastructure

The study team visited more than 50 sites across the three states for perishables assessment. Below are the broad-level observations gathered from the visits.

In India, packhouses for potatoes are only used in the case of export and processing activities and are predominantly located in Gujarat. This is because of Gujarat's highly industrialised and export-oriented nature, as well as the state's strategic access to ports, which facilitates export. Potatoes meant for domestic consumption are not introduced to a packhouse.

Potatoes are stored in bulk as a single commodity

within cold storage facilities. Many of these storages use outdated and less efficient technology, which presents significant opportunities for modernisation and improvement in storage efficiency.

Export-oriented facilities use much more modern technologies. These facilities employ the most energy-efficient compressors, motors, PUF insulation, and O&M practices. These facilities also consume approximately 20% more energy than a local-consumption facility of the same capacity. This results from the advanced sorting and grading lines, highly mechanised infrastructure, and longer running time of the facility.

The potato supply chain generally uses reefer vehicles only for export activities.

Table 15 below provides further details and insights from the observations made during site visits across the states, highlighting specific infrastructure characteristics, energy consumption patterns and operational strategies.

Table 15 Key observations regarding potato value chain across the assessed states

Parameter	Uttar Pradesh	West Bengal	Gujarat
Infrastructure	A mix of legacy and new cold storages, with some multi-commodity storages around Lucknow	Mostly legacy bulk cold storages	A mix of legacy and new cold storages. However, storages are more modern compared to both UP and WB. Export oriented facilities are also present.
Average age of the facilities	With 70% of cold chain facilities over 20 years old, Uttar Pradesh faces inefficiencies due to outdated technologies. Only 18% are modern (≤ 10 years), indicating a need for significant infrastructure upgrades to improve energy efficiency and operational effectiveness.	West Bengal has 75% of its facilities over 20 years old, the highest among the states, with only 8% being modern. This reliance on ageing infrastructure calls for urgent modernisation efforts to enhance efficiency and reduce energy use.	Gujarat demonstrates a more balanced infrastructure age, with only 30% over 20 years old and 30% modern facilities. This reflects better adoption of advanced technologies, contributing to higher efficiency compared to the other states.

Parameter	Uttar Pradesh	West Bengal	Gujarat
Operating hours	Depends on the utilisation rates of the facilities, but similar in all the three states. Loading months: Operations run 24 hours daily to manage the high volume and ensure efficient cooling to preserve freshness. This period refers to the initial phase post-harvest when potatoes are transported to storage facilities right after the harvest. Storage months: Operations run for 16-18 hours daily. Storage months refer to the period when potatoes are kept in cold storage, focusing on maintaining optimal conditions. End of season: Operations run for 12-14 daily. End of season refers to the final phase where the remaining potatoes are gradually moved out for sale.		
Rent	Rent is not regulated. Observed rent was INR 240 per quintal in Barabanki for normal potatoes and INR 290 for CIPH treated potatoes. In Lucknow, it was INR 290 and INR 340 respectively. Linear increase in rent was observed YoY.	Rent is regulated by the Agricultural Marketing Department. The rent is INR 168 per quintal for 2024. The rent has remained constant over the past four years.	Rent is not regulated. Observed rent was INR 260 per quintal in Gandhinagar. Linear increase in rent was observed YoY.
Technology landscape	Mix of old and modern technologies	Old	Facilities in Gandhinagar adopted mostly newer technologies, including automation and had a positive uptake towards solar PV integration.
Insulation	Different insulation materials in different regions. Lucknow and Barabanki regions were dominated by rice husk. Agra region was dominated by glass wool and Prayagraj region was dominated by thermocol.	Thermocol	The observed facilities were relatively newer and hence were using PUF as the insulation.
Electricity tariff	Increased at a linear rate over the past four years	Remained constant over the past four years.	Increased at a linear rate over the past four years.
Business model	Private/cooperative ownership and trader-based rental business model	Private ownership financing and cooperative and trader-based rental business model	Private ownership and trader-based rental business model

Energy consumption assessment

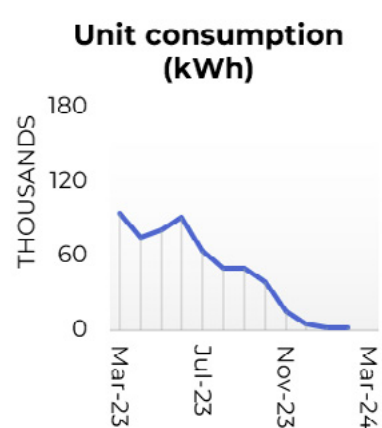
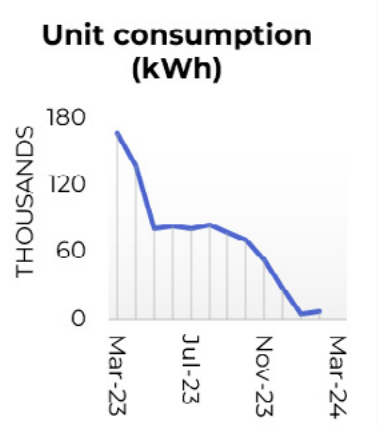
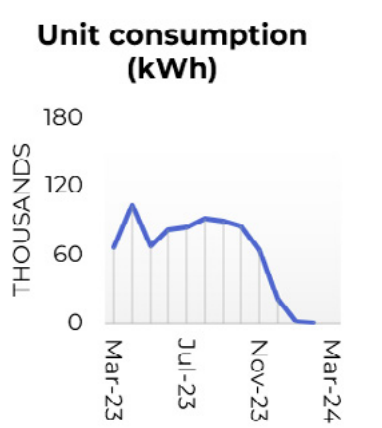
Given the seasonal nature of potato cultivation, it's possible to establish a clear energy consumption pattern for cold storage facilities. While harvesting generally peaks between February and March, potatoes are loaded into cold storage starting in the second or third week of March, concluding by early April. This time difference exists because:

- **Harvesting:** Occurs over a concentrated period (February-March).
- **Post-harvest activities:** Farmers and traders may engage in sorting, grading and packaging before transporting potatoes to cold storage, depending on their capacity and resources. This can create a slight delay between harvest and storage.

A typical storage season then extends for approximately nine months, concluding by late November or early December. This ensures a consistent supply of potatoes throughout the year.

Crucially, the months of December and February are dedicated to essential maintenance, ensuring optimal operational readiness for the next loading season. This cyclical pattern, illustrated in Table 16 below, captures the diverse energy consumption patterns observed across different types of potato cold storage facilities during field visits. While these facilities are not representative of all specifications seen in each state, they highlight how variations in age, technology and operational practices can influence energy use. The examples provide insight into consumption trends across different facility ages and incorporated technologies.

Table 16: Observed energy consumption trend in potato cold storages

	Uttar Pradesh	West Bengal	Gujarat
Facility description	Age: 11 years (Estd. 2014) Type: Single commodity bulk potato cold storage Location: Lucknow Capacity: 8,150 MT Utilisation: 100% in 2024 Technologies: VCM with unit system (MIDH availed) Operating hours per day: 16-18	Age: 48 years (Estd. 1978) Type: Single commodity bulk potato cold storage Location: East Burdwan Capacity: 14,900 MT Utilisation: 100% in 2024 Technologies: VCM with ammonia bunker system Operating hours per day: 14-16	Age: 8 years (Estd. 2017) Type: Single commodity bulk potato cold storage Location: Gandhinagar Capacity: 9,594 MT Utilisation: 100% in 2024 Technologies: VCM with unit system and automation Operating hours per day: 24
Energy consumption trend	 Unit consumption (kWh) THOUSANDS Source: Author analysis	 Unit consumption (kWh) THOUSANDS Source: Author analysis	 Unit consumption (kWh) THOUSANDS Source: Author analysis

The energy consumption of potato cold storage facilities in India follows a distinct seasonal pattern driven by operational needs:

- **Loading season (March-early April):** Energy consumption peaks as freshly harvested potatoes require rapid cooling from ambient temperatures to the target storage temperature.
- **Storage season (April-November):** Once the initial cooling phase is complete, energy consumption stabilises at a relatively constant level, ensuring optimal storage conditions. Towards November, energy use gradually declines as the storage season ends and demand decreases.
- **Maintenance period (December-February):** Energy consumption is minimal during

this period, which is dedicated to facility maintenance and preparation for the next loading season.

Breakdown of energy consumption:

- **Refrigeration system:** This system accounts for most of the total energy consumption ranging from 70-90%, depending on the facility type and structure.
- **Fans:** Used primarily for drying and sorting processes, fans consume a smaller but significant portion (10-15%) of the facility's energy.
- **Lighting:** Constituting a relatively small percentage (5%) of total energy consumption, lighting plays a minor role in the overall energy use.

Policy uptake

This section examines the status of policy adoption in Uttar Pradesh, West Bengal and Gujarat, focusing on key national and state-level schemes. The analysis reveals the regional variations in

policy engagement and its influence on the growth in the cold chain sector across the states. The following Table 17 provides insights into the analysis.

Table 17: Policy uptake in the potato assessed states

Captured states	National-level policy adoption	State-level policy adoption
Uttar Pradesh	Uttar Pradesh leads India in cold chain infrastructure, but uptake of central schemes is limited. The MIDH and NHB schemes see around 50% uptake, mainly in potato-rich areas like Agra and Firozabad, according to consultations with members of the UP Cold Storage Association and facility owners. PMKSY uptake is gradually increasing with more food processing facilities, and many owners use subsidised loans from the AIF scheme.	In Uttar Pradesh, state schemes effectively support the development of cold chain infrastructure, especially in regions like Agra, where uptake of state initiatives has surpassed central ones. The UP Warehousing and Food Processing policies receive positive feedback. Generally, owners prefer the MIDH scheme via NHM for facilities up to 5000 MT, as the state supports it. However, for capacities above 5000 MT, owners are hesitant, as the implementation is handled directly by the NHB (central involvement).
West Bengal	Minimal uptake of central-level subsidies. Consultations with the state government reveal that the capital allocated for central-level schemes often goes underutilised each year. However, some owners apply for subsidised loans through the AIF scheme in the state.	The state food processing policy is the sole scheme for the cold chain sector, but it remains underutilised. Observations from field visits and consultations suggest that the state lag behind others in availing subsidies.

Captured states	National-level policy adoption	State-level policy adoption
Gujarat	Gujarat has positively engaged with national schemes like NHB, MIDH, and PMKSY for developing cold chain infrastructure. Initially, some cold chain operators declined subsidies due to dissatisfaction with MIDH's subsidy cost norms. However, recent revisions are expected to increase adoption.	Gujarat has focused on utilising central schemes for cold chain development. Recently it introduced the Agro Business Policy 2021-26, which aims to enhance agro-processing output. The policy provides subsidies for food processing units, cold storages and reefer vans, among other benefits.

Grape cold chain

Grape Cold Supply Chain Dynamics

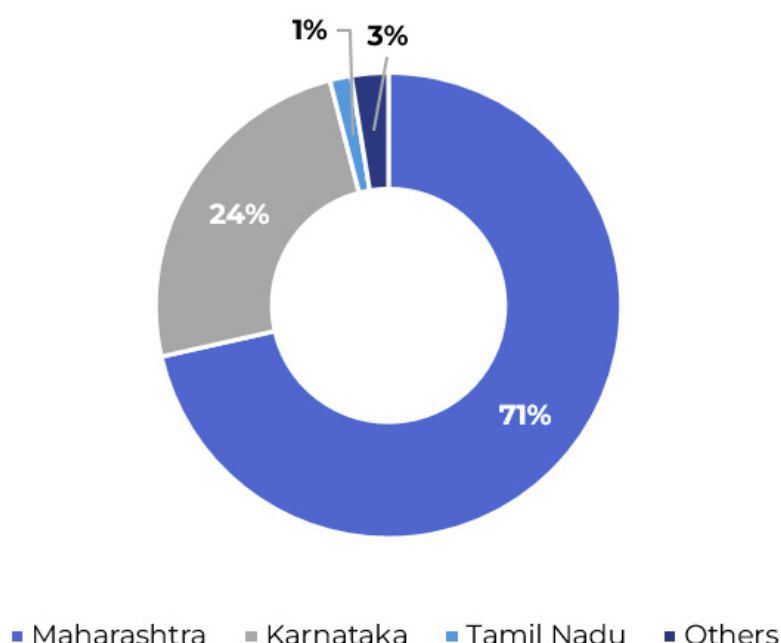
India is a significant player in the global grape market, ranking as the fifth-largest exporter worldwide. In 2021, India's grape production reached 3.35 million metric tonnes, demonstrating its agricultural strength and global trade footprint (Horticulture Statistics at a Glance, 2021). This production is primarily concentrated in a few key regions, with Maharashtra leading the way. Maharashtra accounts for approximately 70% (APEDA, n.d.) of the national grape yield. It is a crucial region in the agricultural landscape and a driving force behind India's grape exports, as over 80% of these exports originate from the state.

Within Maharashtra, Nashik district is particularly influential. It contributes to roughly 73% (NHB, Nashik - Grape Capital of India) of the state's grape output, with significant support from Pune and Sangli districts. Complementing Maharashtra's dominance, Karnataka ranks as India's second-largest grape producer, followed by Tamil Nadu, albeit on a much smaller scale. Together, Maharashtra and Karnataka represent 95% of India's total grape production, highlighting their pivotal roles in this sector.

Figure 11 below presents the state wise percentage split of grapes production in India.

Figure 11 Grapes production by states

Percentage share of grapes production

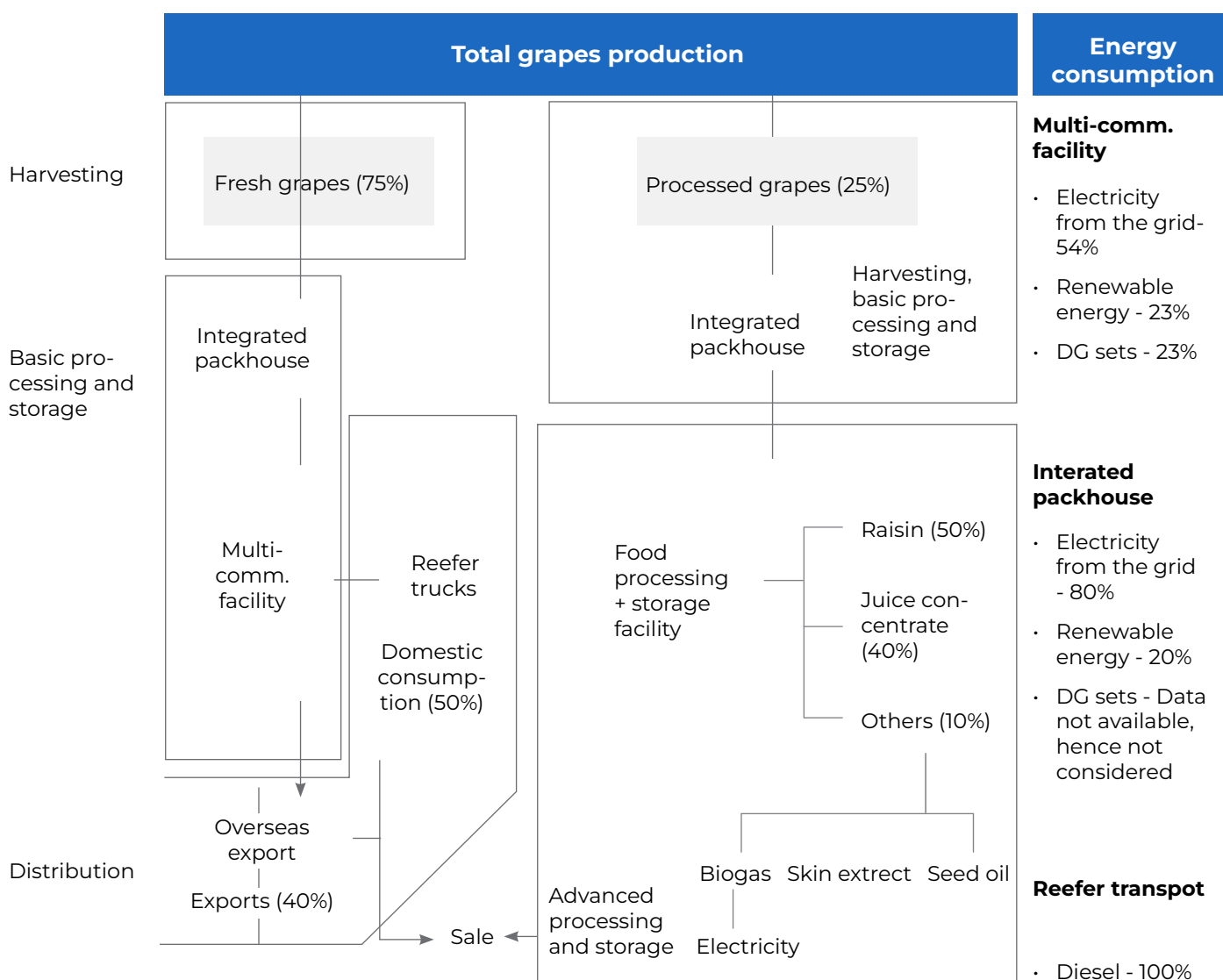


Source: Author analysis

Grapes are a mature and perishable commodity, serving a variety of applications. The approximate distribution between grapes used for direct consumption and those used for processed consumption is in the ratio of 3:1. After harvesting, grapes are typically precooled to reduce their temperature to the desired range of 0°C to 1°C. Following the precooling process, they are generally stored in Type 2 cold storage facilities, also known as multi-commodity cold storages. Unlike potatoes, which often have dedicated

storage facilities, grapes are usually stored in specific chambers within these multi-commodity facilities. From these storage facilities, grapes are either exported or distributed for domestic consumption. In cases where grapes are processed, the grapes of processing quality are transported to the appropriate processing units. These units cater to the production of various end products, such as juice, juice concentrate and raisins. Figure 12 below illustrates a typical grapes cold supply chain in India.

Figure 12: Grapes value chain in India



From field visits, it is observed that most of the infrastructure relating to grapes is highly modern and there is less scope for energy transition. However, the maximum energy consumption can be observed in the processing and storage stages.

Notes:

- The energy consumption for processing facilities is outside the scope of this study
- The energy consumption split for CS facility and integrated packhouse is based on the calculations

Observations from site visits

Grape cold chain infrastructure

Grapes are typically stored in dedicated chambers within Type-2 facilities, which are specially designed to maintain the optimal conditions required for preserving the quality of grapes.

Integrated packhouses are designed to handle the sorting, grading, and packaging of grapes. They primarily focus on differentiating batches for export and food processing, ensuring that the grapes meet the necessary quality standards and specifications for their intended markets.

Food processing facilities are where grapes are

transformed into various products, such as juices, pulp, wines, or dried grapes (raisins). This process ensures value addition and extends the usability of the grapes by creating diverse products that can meet different market demands.

It has been observed that only grapes intended for export or those processed into products are transported using reefer vehicles. This specialised transport is crucial for maintaining the quality and freshness of the grapes or grape products during transit.

Table 18 below provides key cold chain infrastructure observations for grapes value chain.

Table 18: Key observations in grapes cold chain infrastructure

Parameter	Key observation
Infrastructure	Grapes meant for exports and food processing are stored in Type 2 facilities (multi commodity). Export and processing-oriented grapes also pass through an integrated packhouse and through reefer vehicles from logistics point of view. Another variety of grapes which are commonly stored across Maharashtra are raisins, also called dried grapes. These are stored in Type 4 facilities, mostly near semi-urban and rural regions. Highly urban centres like Mumbai, Pune and Nashik usually cater to exports and processing of grapes.
Operating hours	For export and processing-oriented grapes, the operating hours cannot be determined exactly. Export- oriented grapes are stored in Type 2 facilities, which have very dynamic operations. Compressors usually run 24 hours a day for the entire year. This again depends on the portfolio of produce stored in the facility. For storage of raisins, the generally observed trend is similar to any Type 4 facility, which is 8-10 hours of compressor running time.
Rent	The rent is dynamic, and it varies from region to region, weight, and duration of storage in the facility. Approximately, facility owners charge INR 7- 8 per kg for 15 days storage. This number will be different for storage and food processing (depending on the type of product) as well as raisins.
Technology landscape	Export and processing-oriented facilities are equipped with highly modern technologies, including efficient compressors, evaporative condensers and solar PV. The reefer vehicles are vapour compression based, with R-134a as the refrigerant in use. The Type 4 facilities that store raisins are typically less efficient due to older technologies. The observed compressors are the KC4 series. The facilities use IE1 pump motors and water-cooled condensers. There is an average uptake of solar PV integration.

Parameter	Key observation
Training and capacity building	Technicians and operators are usually trained on the job. In tier 1 cities like Mumbai and Pune, the technicians/operators can be hired from ITI institutes. However, owners prefer to hire people and train them on the job since this results in lower costs for the owners.
Insulation	PUF/PIR in Type 2 facilities and food processing units. Thermocol in Type 4 facilities.
Electricity tariff	There are two types of tariffs observed in Maharashtra: industrial tariffs and agricultural tariffs. Cold chain is applicable under both these tariffs. However, in agricultural tariffs, the facility strictly requires to only store agricultural produce like fruits, vegetables, spices and lentils. No dairy or frozen food can be stored, and in addition, no food processing can be done. As a result, many of the facility owners choose to opt for the industrial tariffs. From consultations, it is known that the tariff rate difference between agricultural and industrial tariffs in Maharashtra is significantly less.
Business model	Distributor rental and B2B rental are the most observed models when it comes to storage of grapes. Some facilities also have their in-house processing units. Such type of facilities usually operates on two types of models, which are solely rental and rental and processing.

Energy consumption assessment

Unlike potatoes, which predominantly utilise dedicated cold storage, grapes in India are often stored in multi-commodity facilities (Type 2) alongside products like dairy, frozen peas, spices and other fruits. Due to the diverse storage requirement, ranging from sub-zero temperatures, and chiller temperatures. Refer to Table 30 for more details.

Several factors contribute to the higher energy consumption observed in these facilities:

- **Grape processing:** Transforming grapes into value-added products like juices, wines and raisins demands significant energy input.
- **Rapid cooling requirements:** Grapes, being highly perishable, necessitate rapid cooling from ambient temperatures (around 30°C in regions like Maharashtra) to approximately 1°C. This drastic temperature reduction requires substantial energy, especially for export-bound grapes.

- **Stringent export standards:** Meeting international quality standards for exported grapes necessitates advanced cold chain infrastructure with sophisticated technology and rigorous operational practices. This emphasis on quality, particularly in regions like Maharashtra, limits the scope for energy-saving interventions in existing facilities.

The advanced nature and inherent energy intensity of grape cold storage, particularly for export, contrasts with potato facilities, where energy efficiency improvements might be more feasible. Energy intensity in India's Grape Cold Chain is a shared infrastructure challenge. This highlights the need for tailored energy strategies within India's cold chain sector, acknowledging the unique demands of different agricultural commodities.

Policy uptake

This section highlights the status of policy adoption in Maharashtra concerning national and

state-level initiatives. The table below provides insights into the analysis.

Table 19: Policy uptake in the grapes assessed state

Captured states	National level policy adoption	State level policy adoption
Maharashtra	Maharashtra, a food processing hub, has high PMKSY uptake, with 70% of APEDA-registered integrated packhouses located there. The state is also home to India's largest FPO, Sahyadri Farms. This strong infrastructure supports PMKSY. MIDH and NHB uptake are positive but slightly lower.	Maharashtra leads in state-level policies promoting cold chain infrastructure. The state demonstrates strong stakeholder engagement in its cold chain and export-oriented initiatives. The MAGNET scheme, developed by the state government and ADB, aims to enhance energy efficiency in cold chain infrastructure for select perishable value chains.

Chilli cold chain

Chilli is a vital crop within Indian agriculture, known for its diverse applications and significant economic value. It holds a strong position in the mid-value segment of perishable crops. Andhra is the leading producer, contributing to nearly half of the country's chilli production and cultivating more than 15 distinct varieties. This diversification supports various market segments, with each variety tailored to specific uses and commanding different price points.

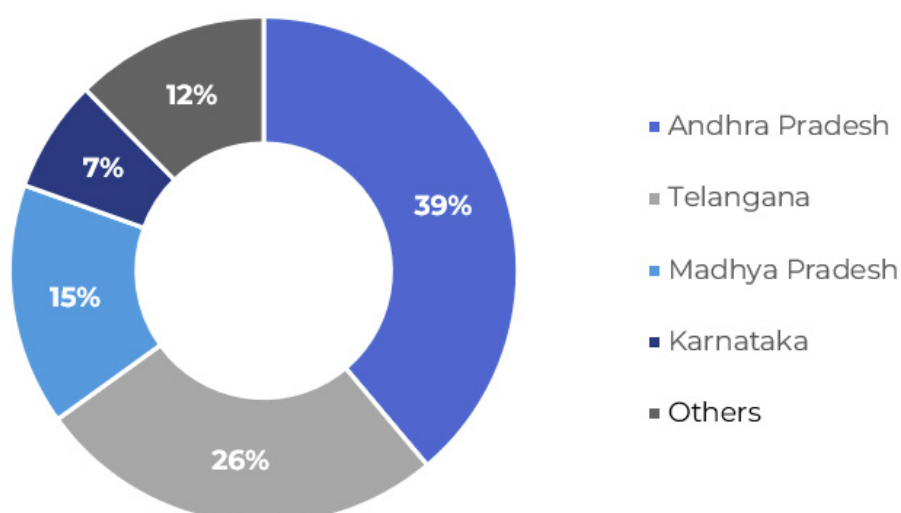
Among the cultivated varieties, the 'Theja' chilli is renowned for its high quality and flavour, making it a coveted export product in international

markets. Additionally, unique varieties like 5531 are utilised beyond culinary uses, such as in red paint production. Other notable varieties, including 355, 999, Super 10, 2043 and Number 5, further enrich the range of chilli peppers available in the market.

Besides Andhra, other significant chilli-producing states include Telangana, Madhya Pradesh and Karnataka, contributing to India's status as a major player in the global chilli market. The state-wise distribution of chilli production is illustrated in Figure 13, highlighting the regional contributions that sustain this vibrant sector.

Figure 13 Chilli production by states

Percentage share of chilli production



Source: Author analysis

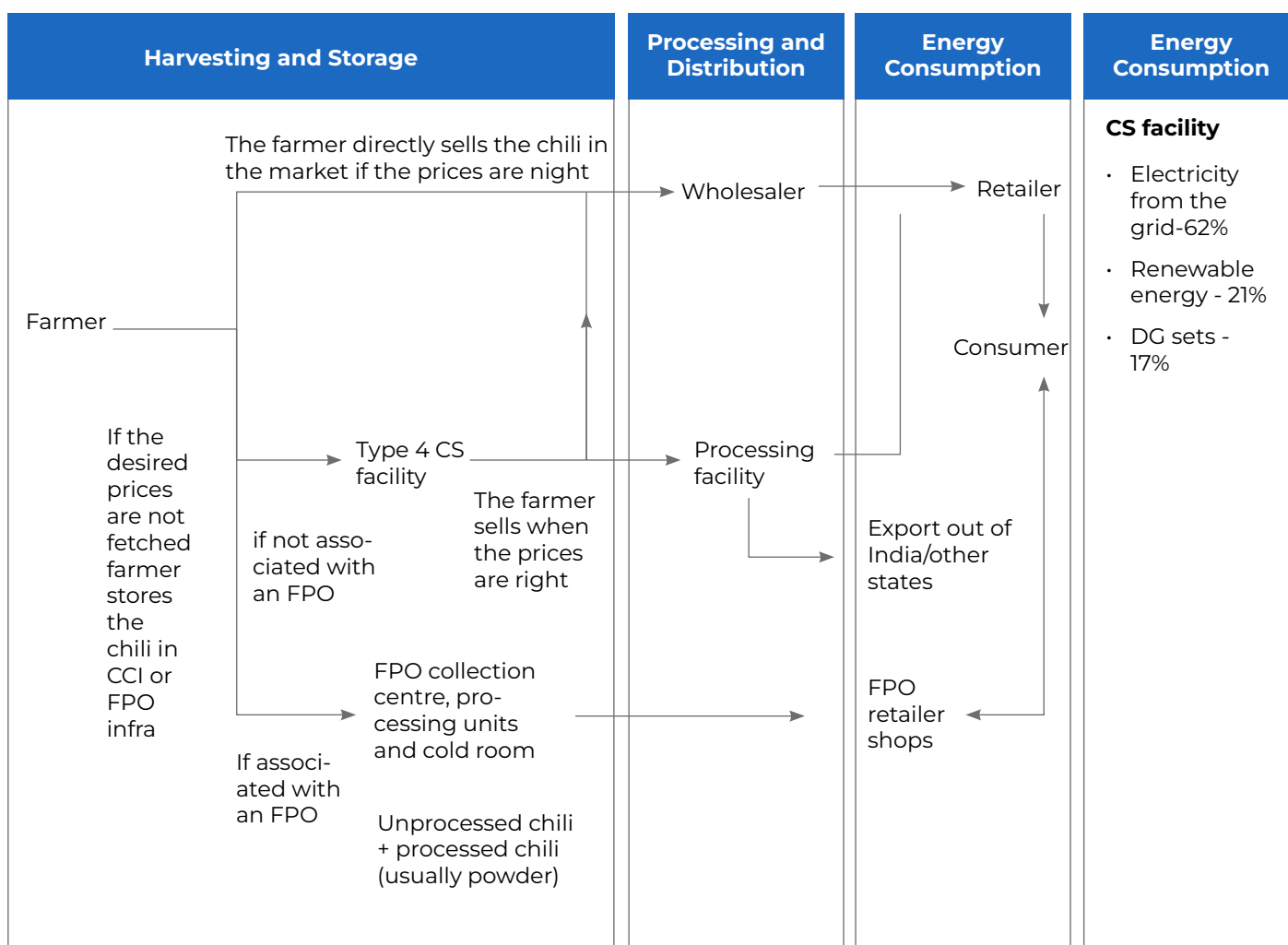
Chilli production in India operates within a dynamic value chain that is heavily influenced by fluctuating market prices. This volatility necessitates adaptable strategies to optimise returns for farmers and maintain product quality. When market prices are favourable, fresh chillies are promptly sold to take advantage of the economic benefits. However, in times of price downturns, chillies are typically stored, often after being processed into chilli powder, which extends their shelf life and adds value.

A significant development in this sector is the rise of FPOs, particularly prominent in Andhra. These organisations play a crucial role in streamlining the supply chain. By centralising the collection, sorting

and processing of chillies, FPOs enable farmers to achieve economies of scale and improve market access. Importantly, FPOs often employ farmgate-level cold rooms as part of their operations. These facilities are crucial in maintaining the quality and freshness of chillies during storage, reducing post-harvest losses and enhancing market readiness.

The chilli cold supply chain thus benefits from these modern practices, which help stabilise income for farmers and ensure a steady supply throughout different market conditions. Figure 14 illustrates a typical chilli value chain in India, highlighting the intricate processes and infrastructure that support this essential agricultural commodity.

Figure 14: A typical chilli value chain in India



The stage with the highest energy transition opportunity is the storage and processing stage, since these consist of the major cold warehouse (type 4) and processing facilities, usually used to convert dry chillis into the powder form, which forms the bulk of the export-oriented products.

Observations from site visits

Chilli cold chain infrastructure

‘The Engineering Guidelines and Minimum System Standards for Implementation in Cold Chain Components’ (NCCD, Engineering Guidelines & Minimum System Standards for Implementation in Cold Chain Component, 2025) recommend that dry spices, dry chillies and raisins be stored in specialised Type 4 facilities. This focus on dedicated storage aligns with Andhra’s dominant cold chain infrastructure, where Type 4 facilities are prevalent, primarily storing chillies and other spices. Furthermore, the adoption of energy-efficient practices is evident in the state, with 111 out of approximately 300 facilities having received the central-level MIDH subsidy. This has resulted in greater energy efficiency than in other facilities

The Horticulture Department of Andhra is actively promoting the establishment of FPOs in the state. FPOs are establishing their own collection centres and farmgate level infrastructure to become self-reliant.

Solar cold rooms are mainly found at the farmgate level, particularly at the FPOs centres. All the associated farmers can store their produce for a specified rent. The Horticulture Department in Andhra has signed an MoU (Memorandum of Understanding) with certain technology providers to develop this infrastructure at the farmgate level. The farmers or FPOs do not have to hire separate consultants and technology providers for this.

In addition, solar poly dryers are utilised at the farmgate level to dry the produce.

Small-scale processing units are established at FPO collection centres to convert the raw materials (dry chilli and turmeric sticks) into the finished product, usually powder.

The Table 20 below provides the key cold chain infrastructure observations for a chilli value chain.

Table 20: Key observations in chilli cold chain infrastructure

Parameter	Key observation
Infrastructure	Type 4 facilities, primarily used for storing chillies, demonstrate a mid to advanced level of energy efficiency technology and solar PV adoption. In Andhra, these facilities boast a solar adoption rate exceeding 60%, significantly higher than other states included in this study. This impressive adoption rate is partly attributed to lower energy requirements of Type 4 facilities, which operate at higher temperatures compared to Type 1 facilities. It is notable that integrated packhouses are utilised exclusively for export purposes. Beyond cold storage, FPOs leverage a network of supporting infrastructure to manage the chilli value chain effectively. This includes: - Collection centres: These centralised hubs allow farmers to deliver their harvested chillies efficiently. - Farmgate cold rooms: Strategically located on farms, these cold rooms ensure optimal chilli quality immediately after harvest. - Solar poly dryers: These energy-efficient drying systems, often powered by renewable energy, contribute to sustainable chilli processing. This integrated infrastructure strengthens the FPO’s multifaceted role in the chilli value chain, encompassing aggregation, processing, storage and marketing.

Parameter	Key observation
Operating hours	Type 4 facilities, commonly used for chilli storage, typically operate their compressors for an average of 15 hours per day throughout the year. However, facility utilisation directly influences compressor running time. For instance, a visited facility operating at approximately 70% capacity operates its compressor for only 8 to 9 hours per day. Integrated packhouses, which handle chilli exports in both raw and processed forms (chilli powder), have more variable operating hours dictated by specific export requirements. Different countries may require varying processing procedures, such as hot water washing, cold water washing, or polishing. These requirements directly affect the facility's operational schedule. This dynamic nature of operation also applies to infrastructure owned by FPOs, which adapt to fluctuating market demands and export requirements.
Rent	In Andhra, chilli storage rental rates are not government regulated. For the fiscal year 2025, the rate for storing one sack of chillies (45-50 kg) was INR 130. This fee encompasses loading, unloading, storage and insurance. The rent is adjusted annually based on chilli production, market prices and storage demand. FPOs determine their own rental rates, with each organisation collectively setting the fee for the financial year. For example, an FPO charged INR 225, which included a comprehensive package of services like collection, sorting or grading, processing into chilli powder and storage.
Technology landscape	Andhra stands out for its proactive approach to integrating energy-efficient technologies and renewable energy into its cold chain infrastructure. The state's horticulture department actively promotes the adoption of these environmentally friendly solutions. Visited Type 4 facilities showcased a range of advancements, including efficient compressor systems, IE3 standard motors, Low Pressure Receiver (LPR) systems, solar PV installations and remote monitoring capabilities. The prevalence of these technologies suggests that approximately 50% of facilities in Andhra have achieved a notable level of energy efficiency, evidenced by their utilisation of MIDH subsidy programme.
Training and capacity building	Andhra, like other states, lacks formal training programmes for cold storage technicians and operators. The industry relies heavily on 'on-the-job' training, which is viewed as the most cost-effective approach, despite the potential benefits of structured capacity-building initiatives.
Insulation	All the Type 4 facilities in Andhra make use of thermocol along with aluminium cladding as the insulation material. Integrated packhouses, ripening units and farmgate level solar cold rooms have been observed to adopt PUF as the insulation. Primarily, Type 4 facilities must maintain temperatures in the range of 8°C to 12°C. To maintain this range, the facility owners are satisfied with thermocol and aluminium cladding as the insulation.

Parameter	Key observation
Electricity tariff	The electricity tariff in Andhra is slightly lower than in the other states visited. The basic unit rate is INR 6.3 per kWh.
Business model	While the chilli value chain shares similarities with the potato value chain, particularly regarding traditional farmer and trader rental models. However, it distinguishes itself by adopting a prominent processing and storage model, especially prevalent among FPOs. Shared models: - Farmer rental: Farmers rent cold storage space directly, managing storage and sales independently. - Trader rental: Traders lease storage facilities, often aggregating produce from multiple farmers before storage and sale. Distinctive model: - Processing and storage (FPO-Driven): FPOs, particularly in Andhra, have integrated processing into their operations. Chillies are often processed into chilli powder before storage, offering several benefits like: - Extended shelf life: Powdered chillies have a longer storage life compared to raw chillies. - Value addition: Processing increases the market value of the product. - Reduced storage volume: Powdered chilli requires less storage space than raw chilli. This FPO-driven model highlights a key difference in the chilli value chain, where processing is often intertwined with storage, unlike the potato value chain, which primarily focuses on storing the raw product.

Energy consumption assessment

Unlike potatoes, which are associated with a well-defined storage season, chilli storage in Andhra presents unique and irregular energy consumption patterns. These variations arise primarily because chilli storage is driven by market conditions rather than predictable seasonal cycles.

Farmers tend to sell fresh chillies immediately when market prices are favourable, resulting in lower volumes of produce entering cold storage facilities and thus reducing energy consumption during these periods. However, when market prices are unfavourable, farmers prefer to store

their produce, often converting it into chilli powder, to preserve quality and wait for better price opportunities. This situation leads to increased demand for cold storage and, consequently, a rise in energy consumption.

This reliance on shifting market rates, rather than fixed seasonal schedules, accounts for the lack of a consistent energy consumption trend in chilli storage facilities. As a result, cold storage operators must remain adaptable, ready to adjust their energy usage in response to market fluctuations.

Policy uptake

The Table 21 highlights the status of policy adoption in Andhra Pradesh concerning national and state-level initiatives, including schemes and subsidies, aimed at developing the post-harvest cold chain sector.

Table 21: Policy uptake in the chilli assessed state

Captured states	National-level policy adoption	State-level policy adoption
Andhra Pradesh	In Andhra, approximately 111 out of 300 facilities have availed the MIDH subsidy, showing a positive response. The RKVY scheme also receives good uptake, particularly through FPO-based models that combine MIDH and RKVY for nearly 70% CAPEX subsidies. PMKSY uptake is gradually increasing due to the establishment of integrated packhouses. Stakeholders show slight hesitation in availing the NHB subsidy, as it removes the involvement and support of the state government.	The Andhra government introduced the AP Food Processing Policy in 2024 to enhance cold chain infrastructure, however uptake data is not yet available. The state is also developing an integrated cold chain policy to promote comprehensive growth in the sector.

6.2. Findings from the assessment of perishables cold chain in India

The study assessed the perishables and the potential for energy transition in India's cold chain infrastructure, focusing on perishables like potatoes, grapes and chilli. It identified Uttar Pradesh and West Bengal as having a higher potential for energy transition due to their outdated cold storage facilities, primarily bulk cold storage units established in the late 1990s and early 2000s.

- Further, the assessment highlighted that a significant portion of the infrastructure was over 20 years old, particularly in states like Uttar Pradesh and West Bengal, where 70% and 75% of facilities, respectively, fall into this category. In contrast, Gujarat shows a more modern infrastructure profile, with 80% of its facilities being 10 years old or newer. Maharashtra and Andhra also have a considerable percentage of newer facilities, with 20% and 90% of their infrastructure being 10 years old or newer, respectively. This age distribution indicates a need for modernisation in states with older facilities to enhance energy efficiency and support energy transition efforts.
- These states show limited adoption of energy-efficient technologies and require modernisation. In contrast, Maharashtra and Andhra have newer facilities with integrated packhouses and solar cold rooms, indicating a relatively lower potential for energy transition.

- The assessment highlights diverse business models and financing mechanisms, involving private, cooperative, and FPOs. Infrastructure age and technology adoption vary significantly, with Maharashtra and Andhra embracing modern technologies and solar photovoltaic (PV) systems.
- The assessment suggests that states with older infrastructure should prioritise upgrading to improve energy efficiency and reduce costs. It also emphasises the role of exports and food processing in driving energy transition, with Gujarat leading in newer infrastructure and technology adoption.

Overall, the assessment underscores the need for targeted interventions to modernise cold chain infrastructure, promote energy-efficient technologies and integrate solar PV systems, particularly in states with older facilities and high potential for energy transition. The tables below provide a gist of observations from perishable value chain assessment and help identify where the opportunity for energy transition exists. The Table 22 provides an overall assessment of key parameters to identify the states with the highest potential for energy transition.

Table 22: Field observations from perishables value chain assessment

Assessment parameter	Uttar Pradesh	West Bengal	Gujarat	Maharashtra	Andhra Pradesh
Perishables assessed	Potato	Potato	Potato	Grapes	Chilli
Type of infrastructure observed (not specific to the perishable assessed)	• Cold storage bulk (Type 1) • Reefer vehicles	• Cold storage bulk (Type 1) • Cold storage hub (Type 2)	• Cold storage bulk (Type 1) • Cold storage hub (Type 2) • Integrated packhouse • Reefer vehicles	• Integrated packhouse • Cold storage hub (Type 2) • Cold storage bulk (Type 4) • Ripening chambers (Type 3) • FPO collection centre • FPO processing units • FPO processing units • Processing units • Reefer vehicles	• Cold storage bulk (Type 4) • Solar cold rooms at farmgate level • Solar poly dryer • FPO collection centre • FPO processing units • Integrated packhouse • Gamma irradiation centre • Ripening chambers (Type 3)
Average utilisation (2024)	90-100%	60-70%	70-80%	70-90%	70-80%
Relative age of facilities	Old – Mid Average age: 20-25 years	Old Average age: 30+ years	Mid Average age: 15-20 years	Mid Average age: 15-20 years	Mid - New Average age: 10-15 years
Business models	Rental, trader-rental	Trader-rental	Rental, trader-rental	Rental, trader-rental, distributor rental, B2B, food processing + storage, food processing	Rental, trader-rental, food processing + storage
Financing mechanisms	Private, cooperative	Private, cooperative	Private, cooperative	Private, cooperative, FPO	Private, cooperative, FPO
Exports landscape	Low	Low	Mid	High	Mid
Existing technology landscape	Old – Semi modern	Old	Semi modern – modern	Semi modern – modern	Semi modern – modern

Note:

- Old technology: Outdated technologies, which include ammonia bunker coil refrigeration system, thermocol/rice husk/glass wool insulation, IE1 condenser and compressor motors, older compressors, with mostly no LPR system installed.
- Semi modern technology: A mix of new and old technologies, which include facilities with older compressors and motors with unit system, PUF/PIR insulation, and monitoring system, mostly have LPR.
- Modern technology: Newer technologies, including unit refrigeration system, PUF/PIR insulation, IE3/4 condenser and compressor motors, new compressor models, and complete automation of the facility.

Table 23 below provides an overview of the age of the infrastructure, implementation of the common energy-efficient technologies, insulation installed and the uptake of solar PV, to understand the state-level scenario for energy transition.

Table 23: Field observations on opportunities for energy transition in the assessed states

Assessment parameter	Particulars	Uttar Pradesh	West Bengal	Gujarat	Maharashtra	Andhra Pradesh
Age of infrastructure	>20 years	70%	75%	30%	60%	30%
	11-20 years	12%	17%	40%	20%	10%
	≤10 years	18%	8%	30%	20%	60%
Technology implementation	EE compressors and pumps	0%	0%	40%	20%	80%
	IE3/IE4 motors	<10%	0%	100%	20%	80%
	BLDC fans	0%	0%	NA	NA	NA
	LPR	~20%	10%	100%	80%	80%
	Remote Monitoring System	~10%	0%	100%	20%	Only for Solar
Insulation installed	PUF/PIR	18%	0%	100%	80%	0%
	Other insulation	82%	100%	0%	20%	100%
Integration of solar PV	Percent of the visited facilities	47%	8%	100%	60%	100%

Notes:

- This table is prepared based on field visit assessment as well as consultations.
- This analysis categorises facility age based on the typical 20-year lifecycle of refrigeration systems.
- It's important to note that the data reflects observations from specific field visits and doesn't necessarily represent the entire state.
- For example, Gujarat's data primarily originates from the Gandhinagar region, known for its newer infrastructure focused on exports and food processing. This explains the higher adoption of energy-efficient (EE) technologies compared to Uttar Pradesh and West Bengal.

Observation

- Age profile underscores the need for modernization: UP ~70% and WB ~75% of facilities are >20 years old; Gujarat is largely modern with ~80% ≤10 years; Maharashtra ~20% ≤10 years; Andhra ~90% ≤10 years.
- Older states show limited adoption of energy-efficient technologies and require targeted upgrades; Maharashtra and Andhra exhibit newer assets with integrated packhouses and solar cold rooms.
- Business models and financing are diverse—private, cooperative, and FPO-led—varying by commodity, market orientation, and state.
- Technology adoption is uneven: Maharashtra, Andhra, and Gujarat show stronger uptake of modern systems and solar PV, while UP and WB fall back comparatively.
- Highest energy transition potential is in Uttar Pradesh and West Bengal due to the prevalence of older, bulk potato storages from the late 1990s–early 2000s running on ammonia bunker systems.
- Priority action: upgrade legacy facilities in older clusters to cut energy use and operating costs and improve reliability.
- Export orientation and food processing capacity are important drivers of modernization and energy transition; Gujarat is comparatively advanced on both fronts.
- Potato cold storages: Uptake hinges on state involvement—UP's state schemes often outperform central ones, West Bengal underutilizes subsidies, and Gujarat's adoption of central schemes is strengthening with revised MIDH norms.
- Grape cold storages: Maharashtra leads with high PMKSY uptake, supported by a dense integrated packhouse base (about 70% of APEDA-registered IPHs) and proactive state initiatives like MAGNET.
- Chilli cold storages: Andhra Pradesh leverages FPO-based stacking of MIDH and RKVY to reach nearly 70% CAPEX support, with PMKSY uptake gradually increasing and some hesitation toward NHB.

7. Key Takeaways from National and State Level Perishable Assessment

7.1. Supply chain analysis

The cold chain sector in India operates through a multi-tiered supply chain that spans from the farmgate to the mid or hub level and finally to the last mile or distribution level. Each level plays a distinct and critical role in maintaining the integrity and quality of perishable goods as they move from production to consumption. Understanding the unique infrastructure, technological advancements and challenges at each level is essential for identifying opportunities for improvement and implementing effective energy transition strategies.

The farmgate level is the starting point for perishable goods, where initial efforts to preserve

product quality begin. However, the concentration of infrastructure at this level remains limited, highlighting a gap that needs to be addressed to reduce post-harvest losses and enhance farmer incomes. In contrast, the mid or hub level features a more developed infrastructure network, driven by a more stable electricity supply and proximity to urban areas. Despite this, substantial opportunities exist for energy conservation and efficiency improvements at this stage. Lastly, the distribution level encompasses the critical transition from static to mobile infrastructure and plays a crucial role in the delivery of perishables to end consumers.

Farmgate level

Infrastructure:

- Traditionally, most of India's cold chain infrastructure is concentrated at the mid or hub level, where electricity supply is relatively stable. Packhouses, ideally required at farmgate level, are established closer to the mid-level, not solving the required purpose of catering to farm-level challenges.
- Comparatively, only fewer facilities (standalone cold storages) exist at the farmgate level.

Technology:

- These cold rooms are either conventional grid based (which face challenges of interrupted power supply) or are majorly solar PV-powered cold rooms, usually with a capacity of 10-20 metric tonne.
- Despite the government's efforts, adoption of renewable energy-based cold rooms at the farmgate level has been gradual. Most notably, solar PV-based cold rooms have been

observed in states such as Maharashtra and Andhra. In contrast, biogas-based cold rooms were not observed during field visits.

- Solar PV-based cold rooms are often found at aggregation centres belonging to FPOs. Maharashtra and Andhra have a strong uptake of the FPO model, which explains the presence of this infrastructure in these states, unlike in potato-dominant states such as UP, WB and others.

Additionally, the NCCD has established a demonstration unit of an off-grid solar PV-based cold room at their Gurugram office. This highlights the government's prioritisation of this infrastructure as a crucial step towards ensuring food security in India.

To improve farmers' incomes and reduce post-harvest losses, India focuses on strengthening farmgate infrastructure through schemes or subsidies like the MIDH, NHB and AIF.

Mid or hub level

Infrastructure:

- Most of the cold chain infrastructure is concentrated at mid or hub level near urban and semi-urban areas, where the grid provides a more stable and reliable electricity supply compared to the farmgate level. As a result, many farmers choose to bypass farmgate-level infrastructure and directly store their harvested produce in these mid-level cold storage facilities. This trend is particularly evident in potato-producing states such as Uttar Pradesh, West Bengal, and, to some extent, Gujarat.
- Cold storages (bulk/multi) form much of the infrastructure found at this level. However, as mentioned earlier, packhouses and aggregation centres are also found in the mid/hub level and not very close to the farmgate level.

Technology:

- Vapour Compression system form the majority. Bulk cold storages like for potatoes/chillies predominantly have ammonia bunker systems for refrigeration while the multi-cold storages run primarily on freon-based unitary systems.
- In cases where bulk cold storages avail subsidies from NHB/NHM, the ammonia-based unitary system is installed.

The mid or hub level remains a critical stage with significant potential for energy conservation. By implementing more efficient technologies and transitioning to renewable energy sources, these cold storage facilities can reduce energy consumption and lower operational costs. This represents a substantial opportunity for energy transition, as these facilities can adopt renewable energy, energy-efficient refrigeration systems and advanced energy management practices.

Last mile or distribution level

Infrastructure/application:

- This stage primarily involves the usage of mobile infrastructure like refrigerated and non-refrigerated vehicles. From a horticultural perspective, in India, very few perishables are transported through refrigerated vehicles. Most of these are predominantly fruits like apples, grapes and kiwi, which require lower storage temperatures. Only in the case of exports, are perishables transported through refrigerated vehicles due to stringent requirements.

Technology:

- Most of the refrigerated vehicles operate on the traditional vapour compression system.

- Electric vehicles (EVs) were not observed in any of the states visited, not even the export-oriented vehicles. This suggests that even though EVs have been promoted by the government, their uptake has been very low. This can be attributed to the fact that EVs tend to cost more than traditional internal combustion (IC) vehicles.
- Digitisation includes the use of GPS and sensors for temperature and humidity monitoring.
- The NCCD, in its revised engineering guidelines, has attributed a higher cost norm for refrigerated EVs compared to refrigerated IC vehicles. This move should, it is hoped, increase the uptake of EVs in the refrigerated transport sector.

7.2. Technological landscape

Based on the assessment of perishables and consultations with stakeholders, the findings from the technology landscape can be categorised into static and mobile infrastructure. Static infrastructure includes packhouses, cold storage facilities (both hub and bulk) and ripening chambers, which are essential for maintaining the integrity and quality of perishable goods.

Meanwhile, mobile infrastructure comprises refrigerated transport vehicles, also known as reefer vehicles, which play a critical role in ensuring that perishables are kept at optimal temperatures during transit. This categorisation allows for a focused exploration of technological advancements and their applications across different facets of the cold chain sector.

Technologies in static infrastructure

Static infrastructure plays a pivotal role in preserving the quality and extending the shelf life of perishable goods post-harvest. Technologies incorporated within packhouses, cold storage facilities and ripening chambers are critical for ensuring that produce remains fresh and meets food safety standards. Due to their continuous operation and extensive cooling requirements, static infrastructure accounts for a significant portion of energy consumption within the cold chain sector. Understanding the current technology landscape of static infrastructure is crucial for developing an effective energy transition

roadmap. By identifying and evaluating existing technologies and practices, stakeholders can pinpoint areas for improvement and opportunities to integrate cleaner, more efficient solutions. Implementing state-of-the-art technologies not only reduces energy consumption and operational costs but also ensures that the sector's growth aligns with broader national goals for environmental stewardship and economic advancement. The following Table 24 provides an overview of the current technological landscape in static infrastructure.

Table 24: Technological landscape in existing static infrastructure

	Packhouses	Single-commodity bulk storage	Multi-commodity bulk storage	Ripening unit
Refrigeration system/technology	Cooling required in precooling chambers and staging cold rooms. Vapour Compression Refrigeration (VCR) Forced air for pre-cooling or room cooling (passive VCR) predominant	Vapour Compression Refrigeration (VCR) Ammonia bunker-based system predominant Ammonia/HFC-based unitary system seen in facilities complying with MIDH guidelines and availed subsidy	Vapour Compression Refrigeration (VCR) Unitary system predominant Blast freezing for sub-zero temperatures for the required commodities	Vapour Compression Refrigeration (VCR) – unitary system with artificial ripening ethylene generator is widely used

	Packhouses	Single-commodity bulk storage	Multi-commodity bulk storage	Ripening unit
Refrigerant	R-404 is predominant due to its high Coefficient of Performance (CoP) that helps to pulldown temperature during precooling. However, as per revised NCCD guidelines, R-404A is not recommended.	Ammonia is most used. R134a or R404A also seen in smaller capacity CS (hub/distribution centres).	Both ammonia and freons, predominantly R-404A, observed.	R-404A, R-134a found in most cases. Ripening units within a CS facility are also seen using ammonia. In addition, ethylene used for ripening.
Insulation	PUF observed in integrated packhouses for pre-cooling chambers and staging cold rooms.	Insulation varies by age and region of the facility. Older facilities mostly use thermocol, glass wool and rice husk. The newer facilities see some use of PUF. PIR and VIP were rarely observed.	These are relatively newer - predominantly use PUF. PIR rarely observed. Fewer facilities with thermocol, glass wool also observed.	Generally, PUF observed in ripening units.
O&M	Integrated packhouses - primarily export focused, maintaining strict operational and maintenance standards to meet global requirements. Conventional packhouses - typically lack standardised operation and maintenance practices, operating with minimal oversight.	Older facilities - lack standardised operation and maintenance practices. Newer facilities - comparatively better focus on O&M practices; proactive to some extent.	Management and maintenance of various types of commodities requiring different storage conditions and handling - more focussed on O&M. Facilities dealing in B2B model or tie up with established companies showed more alignment with standardised/stringent practices for better quality control of products and overall efficiency.	Facilities dealing with exports or managed by established players followed a set of predefined practices to ensure perfect ripening while other facilities were also observed with no defined practices and running purely on experience gained over the years.
Digitisation	Limited to integrated packhouses with IoT for temperature monitoring and automated sorting lines. Conventional ones rely on manual work.	Minimal; some newer facilities use basic IoT sensors for temperature. Most depend on manual checks, especially for potatoes.	More prevalent (10-15%) with IoT, RFID for inventory tracking in dynamic setups. Still, many use manual records.	Basic automation in ethylene dosing. IoT is rare. Manual monitoring dominates.

Technologies in mobile infrastructure

Understanding the technological landscape of mobile infrastructure is essential for advancing energy efficiency within the cold chain sector. As the demand for reefer vehicles increases, driven by the need to meet stringent quality standards, it becomes imperative to adopt advancements in vehicle technology to improve sustainability. Reefer vehicles ensure that perishables remain at

required temperatures throughout their journey, minimising spoilage and aligning with food safety regulations.

Table 25 below outlines the technological landscape of refrigerated transport in India, detailing refrigeration systems, refrigerants, insulation, piping, O&M and digitisation practices.

Table 25: Technological landscape in existing mobile infrastructure

Assessment parameter	Refrigerated transport		
Refrigeration system	VCR system integrated to the cargo container – runs on the power generated by the vehicle engine	Phase Change Material (PCM) – PCM stores and releases energy. There is a small VCR system integrated to charge the PCM	Insulated vehicles – No cooling technology is installed. Insulation ensures temperature maintenance for shorter distance travels.
Refrigerant	Only freons are used. Majorly used refrigerants include R134a, R404A. However, as per the revised NCCD guidelines, R22 and R-404A are not recommended and reefers will be unable to avail the MIDH subsidy with these refrigerants.		
Insulation	PUF predominant in reefer containers		
Piping	Commonly used piping material are aluminium, copper and stainless steel		
O&M	Corporate fleets follow maintenance schedules Small operators lack formal O&M, rely on ad-hoc repairs		
Digitisation	GPS and temperature loggers found in corporate reefers/3PL logistic companies and similar. Small operators (80%) use no digital tools.		



7.3. Business models and financing

Business models and financing mechanisms in this sector are vital as they dictate the operational efficiency and scalability of cold chain infrastructure. As India transitions to a more sustainable energy landscape, optimising these

business and financial frameworks is essential for fostering a resilient cold chain system that aligns with national goals for energy transition and climate change mitigation.

Static infrastructure

Business models

The static infrastructure of India's cold chain sector is characterised by diverse business models that cater to varied operational demands.

The Table 26 below illustrates the predominant business models typically observed, ranging from rental arrangements to processing-based systems. The rental model, a prevalent approach, charges users seasonally, offering comprehensive management solutions that encompass

storage, drying, sorting and logistics services. Other models, like trader rental and distributor rental, adapt the rental concept to suit specific commodities or distribution needs, while B2B models and processing systems reflect more specialised alliances and value-added activities. Each model effectively defines the ownership, operational dynamics and strategic focus of static facilities, influencing their capacity to address market challenges.

Table 26: Business models in static infrastructure

Business models	Description	Application
Rental model	Rent is charged seasonally, with additional fees for services such as drying, sorting and logistics, offering a full management solution from storage to distribution.	Typically used in single-commodity cold storages like those for potatoes and ripening units.
Trader rental model	Traders buy potatoes from farmers, store them and sell to wholesalers or local markets. Farmers are paid based on the trader's sales revenue, benefitting from the trader's market expertise and pricing strategies.	Typically used in single-commodity cold storages like those for potatoes and ripening units.
Distributor rental model	Distributors purchase various products, store them and sell to retailers, ensuring a smooth supply chain from producers to consumers.	Common in multi-commodity facilities.
B2B model	Cold storage owners partner directly with manufacturers like McCain, HUL, Nestle and Amul. Manufacturers pay rent based on agreements, simplifying the supply chain by eliminating distributors and fostering direct relationships.	This model has been observed in multi-commodity cold storages.
Food processing and storage model	Combines storage and in-house food processing, allowing facility owners to sell processed foods. This adds value by providing both storage and processing services, creating an extra revenue stream.	This model has been observed in integrated packhouses and food processing-focused cold storages.

Business models	Description	Application
Food processing (including sorting and grading) model	This model charges for services like sorting and grading based on processing type and volume. These services enhance raw commodity value, preparing them for market distribution.	This model has been observed in standard and integrated packhouses.

Financing mechanisms

In the post-harvest agricultural cold chain sector in India, various financing mechanisms support the establishment and maintenance of static infrastructure. These mechanisms play a crucial role in determining the ownership, management and operational dynamics of cold storage facilities. Table 27 below outlines the predominant financing methods observed within the sector, highlighting their descriptions and the extent of their adoption across the country. From private ownership to government-operated facilities, each model offers unique advantages and challenges. These factors influence the overall development and accessibility of cold chain infrastructure in India.

Table 27: Financing mechanisms in static infrastructure

Financing mechanisms	Description	Adoption in India
Capital Expenditure (CAPEX)- private ownership	Involves the owner using their own investment, supplemented by a bank loan if necessary. In this model, the owner is usually the sole proprietor of the facility. Loans are provided by mostly nationalised banks, however, private banks like HDFC have also ventured into this space.	Most common type of financing mechanism observed across the country.
CAPEX- cooperative	Variation of the private ownership model, where multiple owners contribute funds to set up the cold storage facility. The facility is registered under all their names.	This model is also quite prevalent in India.
Farmer Produce Organisation (FPO)	Members of FPO collectively invest in setting up the cold storage facility. These organisations are typically formed by a group of farmers who pool their resources to enhance their bargaining power and share the benefits of the facility. Sahyadri Farms in Nashik is an example of this model.	This model has gradually started gaining traction. Many states like Andhra and Maharashtra are promoting the FPO model.
Government owned and financed	Fully funded and operated by the government. The government invests in the construction, maintenance and management of the facility to support agricultural producers and ensure food security.	Very limited facilities are there across the country which are government owned and financed.

Mobile infrastructure

Business models

Unlike static infrastructure, which focuses on the establishment and maintenance of fixed facilities like cold storage units, refrigerated transport requires flexible, mobile solutions to ensure the effective delivery of perishable goods across different regions. This mobility introduces distinct challenges and opportunities in terms of logistics, fleet management and operational efficiency. The business models prevalent in refrigerated transport, as outlined in the Table 28 below, reflect the sector's adaptability and responsiveness to market demands. These models range from third-

party logistics providers that offer temperature-controlled delivery services, to asset-heavy fleet ownership by large companies seeking control over their supply chains. Additionally, cold chain service providers lease reefer vehicles. Last-mile delivery solutions are employed for urban logistics, driven by the rise of e-commerce and food delivery services. Each model offers unique benefits that shape the operational dynamics and strategic decisions within India's refrigerated transport landscape.

Table 28: Business models in refrigerated transport

Business model	Description	Application
Third-party logistics (3PL)	Logistics companies offer refrigerated transport services for industries like food, pharmaceuticals and chemicals. These companies either own or lease fleets to ensure temperature-controlled delivery of perishable goods.	Most widely used model in India. The owners charge rent to the customers based on the distance covered and duration of usage of vehicle. The target group is primarily distributors/traders.
Asset heavy fleet ownership	Large companies, particularly in food and pharmaceuticals, invest in their own refrigerated vehicles. This allows them to control their supply chain, manage transportation and storage, and ensure compliance with quality standards. Owning a fleet offers flexibility to tailor logistics operations and swiftly adapt to market changes.	Big organisations like Sahyadri Farms, Amul, etc. use this model
Cold chain service	Cold chain owners own and outsource vehicles to their customers.	Cold chain facility owners who own reefer vehicles lease them to distributors/traders and charge a monthly fixed/variable rent.
Last-mile delivery	Smaller refrigerated vehicles are used for quick deliveries of fresh produce, dairy and ready-to-eat meals, essential for modern urban logistics amid rising online grocery shopping and food delivery apps.	E-commerce/quick commerce companies like Amazon, Blinkit, etc. use this model.

Financing mechanisms

The most common way to finance the reefer business is through bank loans. Most of the business owners that the team visited financed their operations with a combination of CAPEX and loans. Another prevalent model in India is leasing, which is favoured by businesses that prefer not to

commit large amounts of capital upfront. Under this model, companies can lease reefer trucks from leasing firms, allowing them to use the vehicles while making regular lease payments. This approach helps preserve cash flow and offers flexibility in fleet management.

7.4. Energy consuming activities in post-harvest agricultural cold chain

- **Production stage:** Energy consumption begins at the production stage with activities such as irrigation and cultivation. Both diesel or gasoline in pump operations and machinery, alongside electricity, especially in greenhouses, are integral. Harvesting predominantly relies on machinery powered by diesel or gasoline.
- **Storage stage:** As perishables move into storage, electricity becomes essential for pre-cooling and refrigeration processes, which are vital for quality preservation and shelf-life extension. Additionally, post-harvest operations like grading and sorting are electricity-driven. Diesel generators often provide backup power to ensure refrigeration continuity in cases of unstable electricity supply.
- **Processing Stage:** The processing of perishables is extensively electricity-dependent, driving crucial activities such as sanitising, cleaning, grading, peeling and cutting. For energy-intensive processes like blanching, drying and freezing, both diesel and electricity are used to manage these operations efficiently.
- **Transport Stage:** Transporting perishables involves a mix of diesel and electricity, ensuring effective delivery and maintenance of product freshness. The choice of transport mode and energy source depends on distance, perishability and logistical considerations.

The Table 29 below reveals the broad level component-wise energy demands across a typical horticultural perishable supply chain

Table 29: Energy consuming activities throughout a post-harvest cold supply chain

No.	Stage of perishable supply chain	Activity	Diesel/Gasoline	Electricity
1	Production	Irrigation	✓ (pumps)	✓ (pumps)
		Cultivation	✓ (machinery)	✓ (greenhouse)
		Harvesting	✓ (machinery)	
2	Storage	Pre-cooling		✓
		Storage/Refrigeration	✓ (DG sets)	✓
		Grading/sorting		✓
3	Processing	Sanitising/cleaning		✓
		Grading/Sorting		✓
		Peeling/cutting		□
		Blanching	✓	✓
		Cooling		✓
		Drying	✓	✓
		Freezing	✓	✓
4	Transport	Transport	✓	✓

Notes:

This study does not focus on production and processing-related energy consumption.

7.5. Cold chain infrastructure energy consumption

The findings indicate that a significant portion, approximately 75%, of storage facilities are dedicated to single commodities, primarily potatoes. Multi-commodity storage facilities, which typically house spices and fruits, account for 20% of the infrastructure. Meanwhile, the storage of pharmaceuticals comprises 5% of the total infrastructure, reflecting its specialised and niche market requirements.

The analysis utilised energy consumption data from 2024, using 2014 as a baseline year, to

identify trends and changes over the decade. The Table 30 below illustrates the energy consumption patterns observed across different components of cold chain infrastructure. These patterns derive from averaging energy consumption based on electricity bills from various facilities in the assessed states. Additionally, the analysis considers average solar electricity generation from solar photovoltaic (PV) installations and average diesel consumption throughout the year.

Table 30: Energy consumption in cold chain infrastructure for reference year (2024)

Cold chain infrastructure	Age categorisation	Percentage of facilities within the age categorisation	Energy consumption pattern (kWh/tonne)				Total energy consumption in 2024 (GWh)	Share of components in total energy consumption
			Grid consumption	RE consumption	Diesel consumption	Total		
Pack-house	-	-	~45-50	~10-15	Data not available	~55-60	~5	<1%
Cold storage (bulk)	>20 years	70%	~45-50	~10-15	~20	~75-80	~1700	33%
	<=20 to 11=>	10%	~45-50	~10-15		~75-80	~300	5%
	<=10	20%	~35-40	~15-20		~70-75	~700	10%
Cold storage (hub)	>20 years	31%	~105-115	~40-45	~40	~190-200	~500	10%
	<=20 to 11=>	50%	~90-105	~40-45		~170-280	~800	15%
	<=10	19%	~80-90	~40-45		~150-170	~300	5%
Ripening chambers	-	-	~5-15	~1	Data not available	~10-15	~2	<1%
Reefer vehicles	-	-	-	-	~5000-5500	~5000-5500	~1000	21%

Notes:

- An average capacity of 60 metric tonne (MT) is assumed for each integrated packhouse, 10,000 MT for a bulk cold storage, 4,000 MT for a hub cold storage, 100 MT for ripening chambers and 10 MT for reefer vehicles, based on site visits.
- Reefer energy consumption is estimated based on diesel consumption, using a conversion factor of 10.7 kilowatt-hours per litre (kWh/L).
- A diesel emission factor of 2.64 kilograms of CO₂ per litre (kg CO₂/L) is applied. The grid emission factor considered for the calculations is 0.757 tCO₂/MW.
- The energy consumption pattern (kWh/ton) numbers have been established from the data collected during site visits.

The analysis of the cold chain infrastructure across various age categories and components reveals significant insights into energy consumption patterns:

Packhouses: With limited data available, packhouses contribute to a minor portion of the total energy consumption, registering ~5 GWh in 2024, which accounts for less than 1% of the overall energy use. This emphasises their lower impact compared to other facility types within the cold chain.

Cold storage (bulk):

- Facilities older than 20 years, which constitute 70% of this category, exhibit the highest energy consumption at approximately 1700

GWh, representing 33% of the total energy share. This highlights the inefficiencies present in older infrastructures.

- Facilities aged 11 to 20 years consume approximately 300 GWh, contributing 5% to the overall energy use.
- Modern facilities (less than or equal 10 years) show relatively better energy efficiency with a consumption of approximately 700 GWh, making up 10% of the total share.

Cold storage (hub):

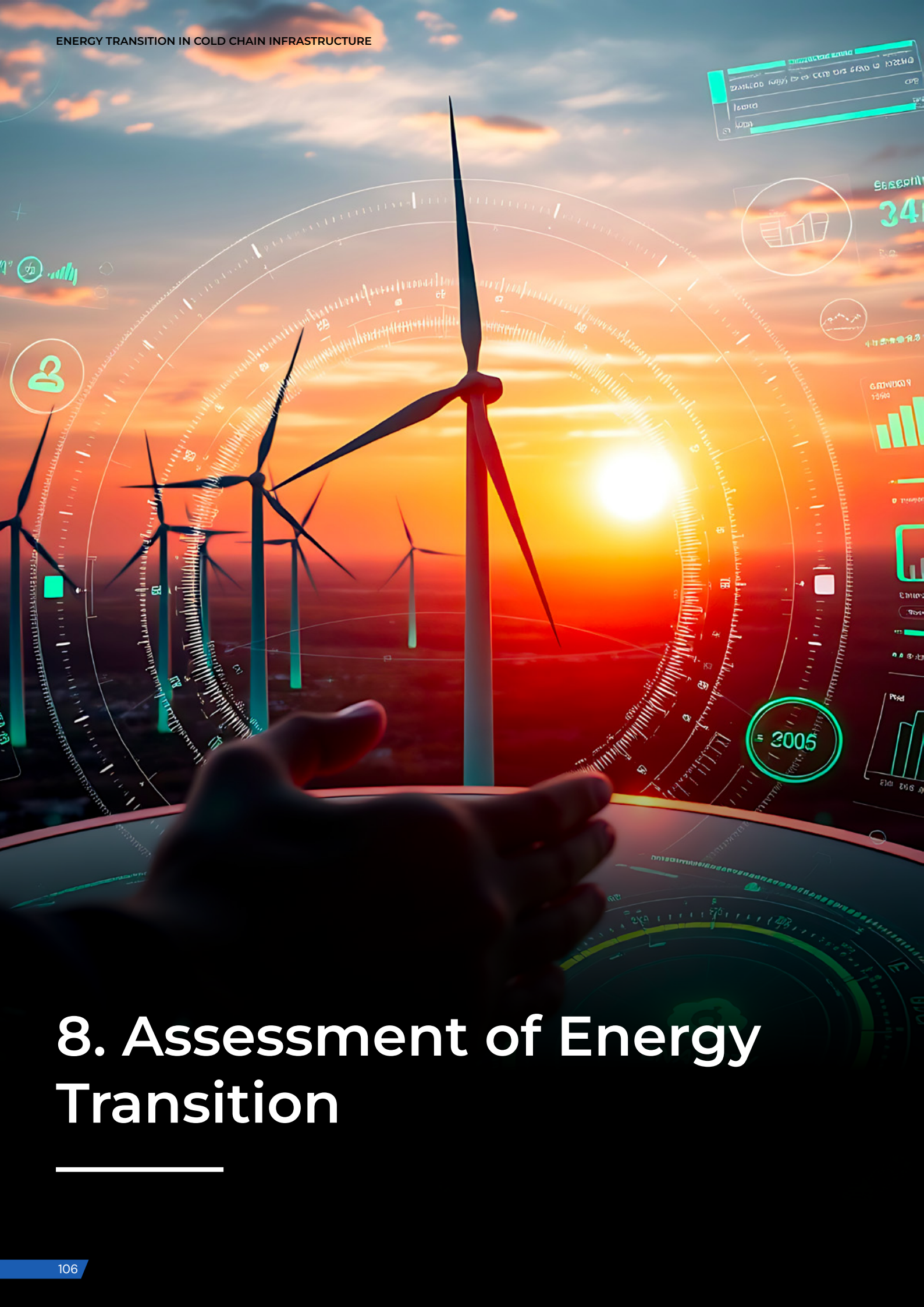
- Older facilities (more than 20 years) account for 31% of the hub category, with a total energy consumption of approximately 500 GWh (10% share), indicating high energy usage due to less efficient older systems.
- Facilities between 11 and 20 years account for the largest consumption at approximately 800 GWh (15% share), showing moderate efficiency improvements over older setups.
- Newer hubs (less than or equal to 10 years) demonstrate better efficiency, consuming approximately 300 GWh, which amounts to 5% of the total energy consumption.

Ripening chambers and reefer vehicles:

- Ripening chambers have minimal energy impacts, with total consumption of approximately 2 GWh, contributing less than 1% of the total energy share.
- Reefer vehicles are significant energy consumers, using approximately 1000 GWh, which translates to 21% of the total energy consumption. This underscores the importance of enhancing energy efficiency in transport logistics to optimise overall energy use.

Observation

- Based on the site visits, only limited farmgate infrastructure were observed: few on-farm packhouses or pre-cooling and only scattered 10–20 MT solar cold rooms at FPO aggregation sites—which pushes most activity to mid/hub facilities near urban centres.
- At hub level, vapour-compression systems dominate, and the largest energy-saving potential exists, older bulk stores typically run ammonia bunker systems, while multi-commodity hubs use freon-based unitary systems.
- Moving downstream, last-mile transport is still mostly non-reefer; reefers are used mainly for exports and low-temperature fruits, with minimal EV uptake. Technology and O&M are mixed across assets: ammonia and HFCs (R134a and the now-discouraged R404A) remain common.
- Older cold storage sites (>20 years) rely on Thermocol/rice husk/glass wool, whereas newer facilities adopt PUF/PIR; digitisation is widespread only in integrated packhouses, and small reefer operators rarely use telematics.
- Older cold storages (>20 years) account for about 33% of overall energy consumption.
- Energy use concentrates in legacy bulk storages over 20 years old (about one-third of total) and reefer fleets (about one-fifth), pointing to clear priorities.
- Small and medium sized cold chain enterprises face the challenge in accessing the capital from financing institutions.



8. Assessment of Energy Transition

8.1. Energy transition – Challenges and opportunities

The transition towards energy-efficient technologies in cold chain logistics presents a strategic opportunity to address both immediate and long-term environmental damage. While cold chain infrastructure holds the potential to revolutionise agricultural supply chains by reducing post-harvest losses and expanding market access for farmers, simply implementing these technologies is insufficient. Existing infrastructure often suffers from significant inefficiencies, leading to high energy consumption and operational costs, which can burden farmers with additional expenses.

This chapter aims to explore both short-term and long-term energy transition prospects, addressing the challenges of adapting the sector to meet modern energy demands. The analysis of energy consumption within various components of the cold chain has revealed critical areas for improvement, particularly in ageing infrastructures and the reefer vehicle segment. Transitioning to energy-efficient technologies and modernising outdated systems are essential steps to curb excessive energy use and align with global sustainability goals.

Before discussing potential pathways for energy transition, it is crucial to highlight the barriers that may impede progress. These barriers include technological limitations, such as outdated equipment that hamper efficiency improvements, financial constraints that restrict investment in modern systems and regulatory challenges that may slow the adoption of innovative solutions. Additionally, a lack of technical expertise and training can hinder the proper implementation and maintenance of energy-efficient technologies.

Understanding these barriers is vital for developing strategic measures that effectively address them. The following sections will outline these strategies, focusing on immediate implementation and long-term pathways. A comprehensive discussion will provide insights into technologies, innovations and methodologies that can catalyse change, fostering the evolution of the cold chain sector in the face of increasing environmental and economic demands.

8.2. Barriers for energy transition

India's cold chain infrastructure, despite its critical role in minimising post-harvest losses and enhancing market access, faces significant challenges in energy transition. Current infrastructure only accommodates about 10% of the country's fresh produce needs, as highlighted by the World Bank (Efficiency for Access Coalition, 2023).

This gap not only leads to economic losses due to food spoilage but also underscores the urgent need for an efficient cold chain system. Moving towards energy-efficient technologies is essential for addressing these inefficiencies, yet several barriers hinder this transition. Key challenges

include technological limitations, financial constraints, regulatory hurdles and a shortage of technical expertise. Overcoming these barriers is vital for unlocking the sector's full potential, which is projected to reach a market value of USD 29 billion by 2038, that could generate 1.7 million jobs (World Bank Group, Climate Investment Opportunities in India's Cooling Sector, 2023).

Table 31 below highlights these barriers in detail, laying the foundation for strategic solutions aimed at fostering a more sustainable cold chain ecosystem.

Table 31: Potential considerations for supporting energy transition in the cold chain industry

Component	Consideration	Observations based on field assessment and stakeholder engagement
Refrigeration system	Initial investment for retrofitting	Energy-efficient refrigeration systems typically involve upfront investment, which may require additional support for small and medium-sized enterprises that are a key part of India's cold chain sector. Many facility owners operate on modest margins, and careful facilitation could encourage wider adoption of retrofitting solutions. In recent EG&MSS renewed focus has been put on Modernisation and induction of more energy efficient equipment.
	Technical considerations in compressor replacement	Upgrading compressors is technically demanding and require planning to avoid operational disruptions. For facilities with scheduled shutdowns, upgrades can be accommodated smoothly, while year-round operations may benefit from phased implementation strategies to maintain efficiency.
	Grid power reliability	While reducing diesel emissions is desirable, clean energy adoption is the need of the time. Some facilities experience temporary grid instability; therefore, supportive measures and stable power availability can further incentivize energy-efficient retrofits.
Refrigerants	Transition costs	Low GWP refrigerants may require system retrofits or replacements. Financial support mechanisms can help small and medium enterprises adopt these environmentally friendly options while ensuring energy efficiency. NCCD in its new guidelines under modernisation, incentivised the change of refrigerants thus paving way towards low GWP refrigerants.
	Availability in the market	Some low GWP refrigerants, particularly HFOs, are currently limited in availability and may cost more than conventional options. Expanding accessibility and supply chains can support broader adoption.
	System compatibility	Existing systems may need modifications to accommodate certain refrigerants. Phased retrofitting and technical guidance can facilitate smoother transitions.
	Safety considerations	Certain refrigerants (e.g., R290, R1234yf) require careful handling due to flammability or pressure characteristics. Training and safety protocols can help mitigate these risks while encouraging adoption.
Insulation	Retrofitting to PUF/PIR	In some regions, traditional insulation materials such as rice husk or glass wool are commonly used. Transition to PUF/PIR can be supported through awareness of long-term benefits and cost-effective implementation strategies.

Component	Consideration	Observations based on field assessment and stakeholder engagement
O&M practices	Standardisation	O&M practices in the fruits and vegetables cold chain are evolving. Guidelines and good practices are available through NCCD and other publications, and wider dissemination and capacity building can help achieve more uniform implementation. NCCD is now conducting workshops across the states in association with stakeholders and pursuing the process of knowledge dissemination and spread awareness.
Subsidies and schemes uptake	Awareness of schemes	NCCD is now conducting workshops across the states in association with stakeholders and pursuing the process of knowledge dissemination and spreading awareness. Stakeholders expressed desire of spreading more awareness on subsidies and Govt. initiatives.
	Cost norms for MIDH	While stakeholders appreciate the support from MIDH, and with the revision of cost norms with the purpose of bringing new technologies, modernisation and energy efficiency is a positive step and encourages further uptake.
Training and capacity building	Standardisation of training	Many facility owners currently provide on-the-job training. Structured capacity-building programs can enhance the availability of skilled technicians and operators, supporting long-term operational efficiency.
Financing	Financial facilitation	Access to financing mechanism remain important for retrofitting and clean energy adoption. Complementary measures, such as interest subvention and bank support, can enable wider adoption of energy-efficient technologies.

8.3. Strategies for implementation of energy transition

This report defines the energy transition for a period encompassing 2025 to 2031, with a focus on immediate steps that can be implemented in terms of passive design interventions, energy efficiency measures, renewable energy integration, and refrigerant switch – defined as energy transition levers. These levers are crucial for addressing the urgent demands of India's energy-intensive cold chain sector. They curb rising energy requirements and enhance sustainability. They provide actionable approaches that can be swiftly adopted to improve the efficiency and environmental impact of this sector, as highlighted below.

Lever 1 - Reduction in energy demand: By optimising the design and construction of cold storage facilities, energy demand can be significantly reduced. This includes strategic building orientation to minimise heat gain, implementing airtight construction to prevent energy loss, and using high-quality insulation to maintain consistent internal temperatures. These measures decrease the load on refrigeration systems, leading to lower energy consumption.

For the development of this report, the study team has focused on one primary intervention based on field assessments. This intervention involves the **replacement of existing expanded polystyrene (EPS) insulation with polyurethane foam (PUF), offering a significantly better U value of 0.022 W/m²K compared to EPS's 0.038 W/m²K**. This change is expected to enhance thermal efficiency and decrease overall energy consumption effectively across the states. While other measures and interventions have been considered, the decision to prioritise this specific strategy stems from its immediate applicability and potential for widespread implementation as a short-term energy-saving measure.

Lever 2 - Improving energy efficiency: Enhancing the energy efficiency of refrigeration systems can be achieved through the adoption of advanced technologies. This includes the use of efficient compressors and motors, Low Pressure Receiver

(LPR) systems, and other modern refrigeration components that require less energy to operate effectively. Regular maintenance and optimisation of existing systems can also contribute to improved efficiency.

For the development of this report, the study team has focused on five primary interventions based on field assessments. These interventions are:

- Replacement of existing fans with energy-efficient Brushless DC motor fans (BLDC fans)
- Replacing the existing water-cooled condenser pump and motor with higher efficiency class motor (IE1 to IE3)
- Replacement of higher efficiency compressors (Only open type compressors have been considered)
- Installation of Remote Monitoring System (mounted on the compressor)
- Installation of Low-Pressure Recovery (LPR) System (for the existing ammonia bunker system)

It is important to note that additional energy efficiency interventions exist beyond the ones mentioned above. These include fully automating the system and replacing traditional water-cooled condensers with air-cooled condensers. However, these alternatives are more difficult to retrofit and involve significant costs. Consequently, they have not been included in this study's list of energy efficiency technologies.

Lever 3 - Shift to renewable energy: Integrating renewable energy sources, particularly solar power, into cold chain operations can substantially reduce reliance on fossil fuels and decrease the strain on the electricity grid. Solar panels can be installed on facility rooftops or nearby areas to generate clean energy, which can be directly used or stored for later use, thus lowering carbon emissions and operational costs.

For this study, the focus on renewable energy is limited to **solar energy sourcing** due to its widespread adaptability and availability. While biogas-based energy is another potential renewable option, it requires access to a consistent and substantial source of waste heat, which is not commonly available in many cold chain operations. Additionally, the infrastructure and processes needed to harness biogas efficiently are typically more intricate and costly compared to solar installations. This makes biogas less feasible for widespread implementation in this context.

Lever 4 - Refrigerant switch: Although switching refrigerants does not directly enhance energy efficiency, it plays a vital role in reducing GHG emissions. Replacing traditional refrigerants like HCFCs and HFCs with options that have lower GWP and ODP, such as natural refrigerants HFC blends, and Hydrofluoroolefin (HFOs), can mitigate the environmental impact of refrigeration systems. The new engineering guidelines developed by NCCD support subsidies for refrigerants with a GWP of 1500 or less.

Under the short-term implementation, the scenarios are defined as follows:

- **Conventional scenario:** This study defines the conventional scenario as a projection of current trends and practices in the Indian cold chain sector through 2031. This includes maintaining the existing utilisation capacity of cold chain components and energy consumption per tonne of produce.

Scenario assumptions: There might be marginal improvement in the O&M as a result of continuous training and capacity building, which may result in certain energy savings across the sector. However, no percentage has been accounted for this in the calculations. The renewable energy penetration

has been assumed at 20% for packhouses, 25% for bulk cold storages, 30% for hub cold storages, and less than 10% for ripening chambers. Approximately 50% of the current energy is sourced from the grid, 30% from renewable energy and 20% from diesel (through DG sets).

- **Energy transition (ET) scenario:** The ET scenario explores the impact of implementing energy savings measures and integrating RE into the cold chain infrastructure. This scenario projects a reduction in grid electricity and diesel consumption and its associated CO₂ emissions. The ET scenario anticipates significant advancements in energy efficiency and increased renewable energy penetration (30% penetration for packhouses and ripening chambers and 40% for bulk and hub cold storages) within the cold chain sector.

Scenario assumptions: The ET scenario assumptions regarding the energy saving potential for various sectors include the following: Integrated packhouses (PH) are assumed to achieve a 10% energy saving potential. For bulk cold storages (CS) of Types 1 and 4, we anticipate energy savings of 30% for facilities older than 20 years, 18% for those between 11 and 20 years, and 10% for those under 10 years. Hub CS of Type 2 is expected to realise savings of 20% for over 20 years, 15% for the 11–20-year range, and 8% for those under 20 years. Ripening chambers (Type 3) are assumed to have a 10% saving potential. We foresee a reduction in diesel consumption due to increased RE uptake and fuel efficiency improvements, estimating a 10% reduction for integrated PH, ripening chambers and reefer transport, and 30% for cold storages (Types 1, 2, and 4). By 2031, we expect RE penetration to increase to 40% for cold storages (both bulk and hub) and 30% for packhouses and ripening chambers.

Implementation in static infrastructure

Lever 1 – Reducing energy demand and lever 2 – Improving energy efficiency

Building upon the defined energy transition levers and measures, there is substantial potential

for energy efficiency improvements in static infrastructure within the cold chain sector. The Table 32 below highlights the estimated potential savings achievable through these strategies.

Table 32: Energy efficiency or conservation measures identified

Measure	Explanation	Estimated savings potential
Replacement of existing fans with energy-efficient Brushless DC motor fans (BLDC fans)	Fans used as a part of the ammonia bunker system as well as in the drying area can be replaced with BLDC fans.	50%
Replacing existing water-cooled condenser pump and motor with higher efficiency class motor (IE1 to IE3)	Replacement to IE 3/IE 4 motors from the current IE 1 motors	8%
Replacement to higher efficiency compressors (Only open type compressors have been considered)	Replacing with compressors which provide minimum 5% energy savings annually.	5%
Installation of Low-Pressure Recovery (LPR) System (for the existing ammonia bunker system)	Maintains optimal refrigerant management and improves system efficiency by ensuring proper liquid refrigerant supply to the evaporators.	8%
Replacement of existing EPS insulation with PUF, with a U value of 0.022W/m ² K against a U value of 0.038W/m ² K of EPS	With better U value and K value than EPS, PUF/PIR is a recommended passive intervention to reduce energy demand.	5%
Installation of Remote Monitoring System (mounted on the compressor) which includes sensors for temperature, RH and other parameters measurement	RMS mounted on the compressor ensures accurate compressor data transmission to the operator/facility owner ensuring effective operations of the compressor.	2%

Note:

- The estimated savings percentage for the above ESMs are as per study team's calculations, based on data collection from site visits and consultations with technology providers.
- It is important to note that there are additional energy efficiency interventions beyond those mentioned above (Water cooled to air cooled condensers, installation of VFDs...etc). However, the ones included above are easily achievable measures and applicable to all the regions and geographies.
- Other interventions like dock levellers/shelters, building orientation etc. may further enhance savings by improving the operational efficiency of the facilities.
- Lever 4 – refrigerant switch has not been considered as a part of this study.

Having identified the potential interventions, the Table 33 further analyses their applicability for specific states assessed during the study.

Table 33: Applicability of energy efficiency measures for static infrastructure in assessed states

States	Observed infrastructure	Switch to BLDC fans	Switch to EE motors	Switch to EE compressors	Installation of LPR	Installation of PUF	Installation of RMS (open type)
UP	Type 1 CS		✓	✓	✓	✓	✓
	Ripening units	NA	NA		NA		
WB	Type 1 CS	✓	✓	✓	✓	✓	✓
	Type 2 CS	✓	✓	✓	✓	✓	✓
GJ	Type 1 CS	✓	✓	✓	✓	✓	✓
	Type 2 CS			□			✓
	Type 1 CS (exports)						✓
MH	Type 2 CS		□	□			✓
	Type 4 CS	✓	✓	✓	✓	✓	✓
	Ripening units						
	Integrated packhouse						
AP	Type 4 CS		✓	✓	✓	✓	✓
	Ripening units						
	Integrated packhouse						
	Solar cold rooms						

Building upon this regional analysis, the implementation of energy efficiency measures in static infrastructure, specifically in potato cold storages, can further enhance the sector's sustainability. The Table 34 below summarises the energy efficiency opportunities across cold

storages in Gujarat, Uttar Pradesh and West Bengal under the energy transition scenario. This comparative analysis illustrates the potential for significant energy savings and emission reductions when transitioning from conventional methods to energy-efficient practices.

Table 34: Energy efficiency opportunity in potato cold storages

Measure	Gujarat		Uttar Pradesh		West Bengal		Total	
	Energy savings	Emissions impact	Energy savings	Emissions impact	Energy savings	Emissions impact	Energy savings	Emissions impact
	GWh/yr	ktCO ₂	GWh/yr	ktCO ₂	GWh/yr	ktCO ₂	GWh/yr	ktCO ₂
Replacement of existing fans with energy-efficient Brushless DC motor fans (BLDC fans)	~7	~5	~79	~60	~35	~27	~121	~92
Replacement of existing EPS insulation with PUF, with a U value of 0.022W/m ² K against a U value of 0.038W/m ² K of EPS	~10	~8	~55	~41	~10	~8	~75	~57
Replacing existing water-cooled condenser pump and motor with higher efficiency class motor (IE1 to IE3)	~4	~3	~20	~15	~4	~3	~28	~21
Replacement to higher efficiency compressors (Only open type compressors have been considered)	~21	~16	~121	~92	~27	~21	~169	~129
Installation of Low-Pressure Recovery (LPR) System (for the existing ammonia bunker system)	~11	~9	~65	~49	~14	~11	~90	~69

Measure	Gujarat		Uttar Pradesh		West Bengal		Total	
Installation of Remote Monitoring System (mounted on the compressor)	~17	~13	~62	~47	~14	~11	~93	~71
Total	70	54	402	304	104	81	576	439

In addition to the assessment of energy transition in potato cold storages, which have the maximum potential for the transition, the study also evaluates the energy transition potential in chilli cold storages, across Andhra Pradesh. These results can be applied at the national level. While chilli cold storages present opportunities for energy savings, the potential is notably lower compared to potato storages.

This difference arises primarily from the larger scale of potato cold storages, which constitute approximately 75% of the total cold storage infrastructure in India. These facilities tend to be older and equipped with outdated technological components, providing a greater scope for

efficiency improvements. Additionally, the storage temperature requirements vary, with potatoes needing to be maintained at temperatures between 0 and 10 °C, whereas chillies require slightly higher storage temperatures between 8 and 12 °C.

The Table 35 below summarises the energy efficiency opportunities in chilli cold storages. It reflects the distinct characteristics and energy demands associated with this type of storage facility. Despite the relatively lower potential in chilli storages, targeted interventions can still yield meaningful energy savings and contribute to the broader energy transition efforts within the cold chain sector.

Table 35: Energy efficiency opportunity in chilli cold storages

Energy Saving Measures	Andhra Pradesh	
	Energy savings (GWh/yr)	Emissions impact (ktCO ₂)
Replacement of existing fans with energy-efficient Brushless DC motor fans (BLDC fans)	~1	~1
Replacement of existing EPS insulation with PUF, with a U value of 0.022W/m ² K against a U value of 0.038W/m ² K of EPS	~3	~2
Replacing existing water-cooled condenser pump and motor with higher efficiency class motor (IE1 to IE3)	~3	~2
Replacement to higher efficiency compressors (Only open type compressors have been considered)	~8	~6
Installation of Low-Pressure Recovery (LPR) System (for the existing ammonia bunker system)	~5	~3
Installation of Remote Monitoring System (mounted on the compressor)	~4	~3
Total	~24	~17

For grapes, calculating the exact energy transition opportunity proves challenging due to the highly dynamic nature of the cold chain infrastructure, which also serves grapes. As highlighted in Table 33 above, switching to energy-efficient compressors, installation of RMS and motors is the only observed energy efficiency measure that can be incorporated.

Calculating the exact energy transition opportunity for grapes proves challenging due to the highly dynamic nature of the associated cold chain infrastructure.

Lever 3 – Renewable energy integration

The transition to renewable energy represents one of the most critical and feasible strategies for advancing energy transformation. This approach significantly contributes to the reduction of energy consumption in cold chain facilities. Observations from site visits indicate that facilities equipped with renewable energy sources, particularly PV systems, can reduce grid electricity consumption by approximately 30 to 50%. Table 36 highlights the possible renewable energy integration scenarios across various levels of the perishables value chain in India.

Table 36: RE integration opportunities

RE integration solutions	Farmgate level	Mid/Hub storage	Reefers
Biomass-powered modular cold rooms	✓		
Solar-powered modular cold rooms	✓		
Solar PV		✓	
Electrification			✓

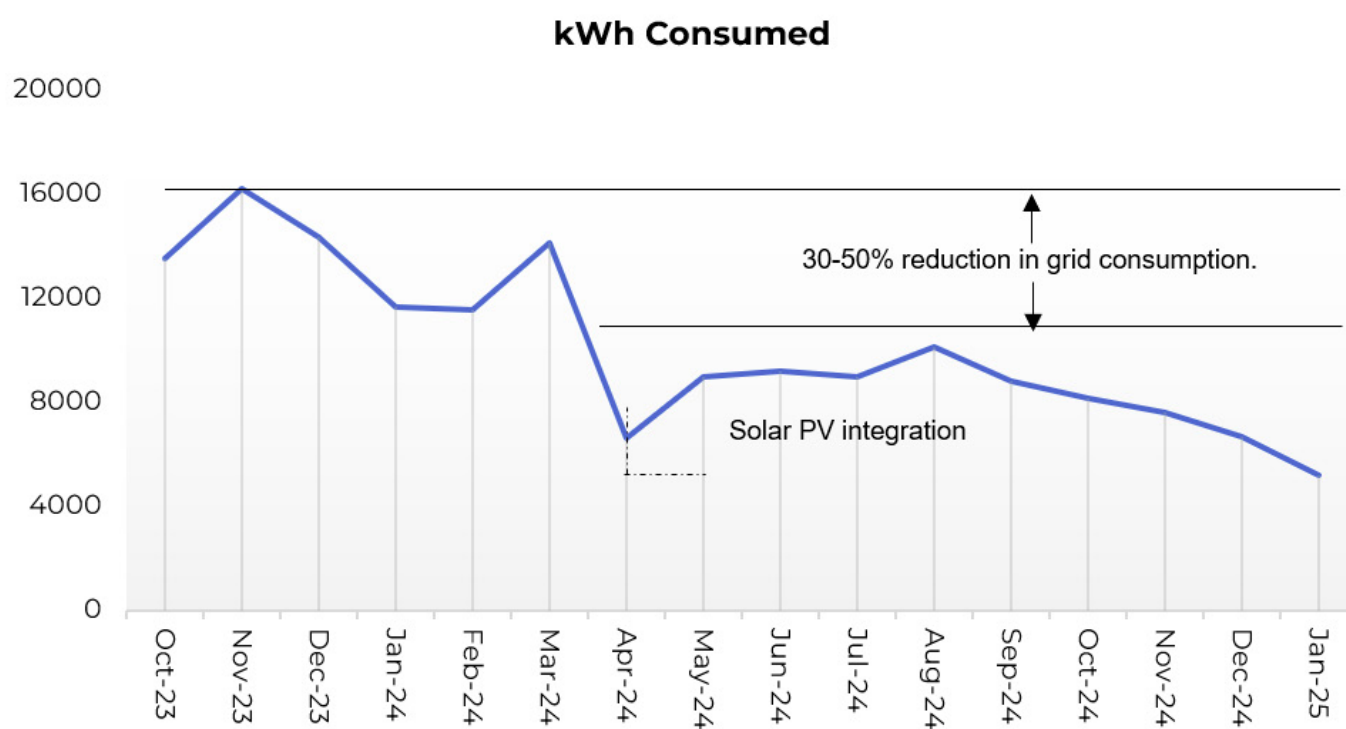
Farmgate level

Solar-powered cold rooms are rapidly gaining popularity in India as observed during field visits. Stakeholders have confirmed that these cold rooms operate entirely off-grid, eliminating reliance on conventional energy sources and promoting sustainability.

Mid-hub level

The mid-hub level of the perishable value chain presents the most significant opportunity for integrating renewable energy sources, particularly PV systems. This level encompasses facilities classified as Type 1, 2, 3, and 4. Figure 15 below showcases the reduction in energy consumption achieved through lower grid dependence at a Type 4 facility in Andhra. This observed grid energy consumption reduction percentage can be estimated to be approximately in the same range in the other geographical location in India.

Figure 15: Roof top solar PV integration in a sample facility



Source: Author analysis

Lever 4 – Refrigerant switch

High-GWP refrigerants (like R-404A, R-410A and R-134a) are powerful greenhouse gases, contributing significantly to climate change. The global movement towards environmentally friendly refrigeration systems is a key driver for this transition. The cold chain industry is transitioning to low-GWP refrigerants to reduce environmental impact, with options like R448A, R407A and R407F emerging as replacements for high-GWP refrigerants like R404A and R410A, while also considering the economic implications of the switch. While there are several low-GWP alternatives already available in the market, the following consideration must be examined while considering the transition.

- **Safety:** Some low-GWP refrigerants, like R-32, are flammable, requiring careful handling and safety protocols.

- **Equipment Compatibility:** Consulting with equipment manufacturers is crucial to ensure proper system design and operation with low GWP refrigerants.
- **Cost:** The cost of low-GWP refrigerants and associated equipment can vary, so a thorough economic analysis is necessary.
- **Performance:** The performance of refrigeration systems using low-GWP refrigerants needs to be carefully evaluated to ensure they meet the required cooling demands.
- **Compliance:** Understanding and complying with relevant regulations and standards is essential.

Table 37 below provides assessment of the refrigerants used in Indian cold chain industry as observed during the site visits under the study.

Table 37: Observed refrigerants in Indian cold chain industry

Commonly used refrigerants	GWP (100 years)	Remarks
R22	1,810	Banned in India under HPMP II, however, it was used as the primary freon refrigerant.
R404A	3,902	Precooling chambers, sub-zero cold rooms, staging cold rooms and ripening chambers
R717 (Ammonia)	0	Type 1, 2 and 4 cold storage facilities
R134A	1,430	Precooling, staging cold rooms and reefers
R407C/R407F	1,824/1,744	Precooling chambers, sub-zero cold rooms, solar cold rooms and ripening chambers

Refrigerant transition progress in India

The HCFC Phase-out Management Plan (HPMP) Stage III (2023–2030) is a pivotal initiative in India's efforts to align with the Montreal Protocol and the Kigali Amendment. It focuses on eliminating hydrochlorofluorocarbons (HCFCs) and transitioning to refrigerants with low GWP and ODP. Building on the achievements of HPMP Stage II (2017–2024), which reduced HCFC consumption by 44% by 2020 (surpassing the 35% target), Stage III introduces strategic measures to advance the adoption of climate-friendly refrigerants. These measures particularly target the refrigeration and air-conditioning (RAC) and cold-chain sectors. The NCCD further supports this transition through updated guidelines, fostering sustainable practices in India's rapidly growing cold-chain infrastructure.

Key developments in HPMP Stage III

Elimination of HCFCs in New Equipment by 2024:

HPMP Stage III targets a complete phase-out of HCFCs in new RAC equipment by 2024, a critical step to reduce ozone-depleting substances and GHG emissions. The plan promotes alternatives such as HFC-32, HC-290 (propane), ammonia, and CO₂, which offer significantly lower GWP and zero ODP, aligning with India's environmental commitments.

Targeted sectoral initiatives: The plan outlines five focused initiatives to ensure a sustainable transition:

- Conversion of 13 RAC manufacturing companies to adopt HFC-32, a refrigerant with a GWP of approximately 675, much lower than traditional HCFCs.
- Support to 48 micro, small and medium enterprises (MSMEs) in the refrigeration sector to transition to HC-290, a natural refrigerant with a GWP of less than 3.

- Expansion of technician training programmes to equip the servicing sector with skills for safe handling of low-GWP refrigerants, addressing critical implementation gaps.

Significant emission reductions: Starting in 2030, HPMP Stage III is expected to reduce emissions by over 19 million tonne of CO₂ equivalent annually, supporting India's obligations under the Kigali Amendment for a phasedown of high-GWP hydrofluorocarbons (HFCs), targeting a 10% reduction by 2032 and 85% by 2047.

Stakeholder collaboration and challenges:

The Ministry of Environment, Forest and Climate Change (MoEF&CC), through its Ozone Cell, collaborates with international organisations, industry bodies and manufacturers to implement HPMP Stage III. Challenges include engaging traders and addressing the use of spurious, low-quality refrigerants. This issue hinders progress. Efforts are ongoing to collect data on HCFC usage to strengthen policy enforcement.

Integration with the India Cooling Action Plan (ICAP):

HPMP Stage III aligns with the ICAP 2019, which aims to reduce refrigerant demand by 25–30% through energy-efficient technologies. By promoting natural refrigerants and efficient systems, Stage III is projected to cut cooling energy demand by 40% and GHG emissions by 400 million tonnes annually by 2030, equivalent to the emissions abatement of 100 gigawatts of solar PV plants.

This study and analysis are limited to the potential investment opportunities associated with transitioning to renewable energy sources and implementing energy efficiency measures and doesn't factor in the potential costs or savings related to refrigerant changes.

Implementation in mobile infrastructure

Reefer transport forms the foundation of India's cold chain logistics and plays a crucial role in various aspects of the nation's growth. Primarily, it is instrumental in reducing food wastage and ensuring food security for a vast population. By minimising post-harvest losses, reefer transport preserves the quality and freshness of India's significant production of fruits, vegetables and seafood from the farm to the market. Additionally, it enables the transportation and storage of seasonal produce, guaranteeing a consistent supply of perishables throughout the year. This contributes significantly to food security. Reefer transport also addresses food safety concerns by maintaining optimal temperatures that prevent bacterial growth and contamination, assuring consumers of high-quality and safe food products.

Beyond food security, reefer transport is a key driver of economic growth and trade. It empowers Indian farmers and food processors to access international markets for their produce, stimulating agricultural exports and generating valuable foreign exchange. Within India, it facilitates domestic trade by connecting production centres to consumption hubs across the country. This ensures a steady supply of perishable goods to meet the demands of a large and geographically diverse population. This robust system further bolsters the growth of related sectors, including food processing, retail and hospitality, and contributes to overall economic development.

Recognising the significance of reefer transport, the Indian government has implemented various initiatives, such as the 'Scheme of Cold Chain, Value Addition and Preservation Infrastructure', to actively promote the development of cold chain infrastructure. With this support, the demand for reefer transport in India is projected to increase significantly in the coming years. This growth is driven by factors like rising incomes, rapid urbanisation, evolving dietary habits and the expansion of organised retail and e-commerce.

Investing in efficient, sustainable and technologically advanced reefer transport solutions is paramount to fully realise its potential and effectively address the challenges of food waste, supply chain inefficiencies and environmental concerns. Below are the types of reefer transport:

- **Trucks:** Dominant mode in India for short-haul and regional distribution due to cost effectiveness and flexibility.
- **Ships:** Crucial for international trade of perishable goods, connecting India to global markets.
- **Rail:** Gaining traction for long-distance domestic transport, offering potential for cost savings and larger cargo capacity.
- **Air:** Primarily used for high-value, time-sensitive shipments, such as pharmaceuticals or exotic fruits, where speed is critical.

Market overview and growth of reefer transport for perishables in India

India's reefer transport market for perishables is undergoing significant expansion, driven by changing consumer preferences, growing industries and proactive government support. Road transport currently dominates the market because it is cost-effective and agile for domestic distribution. The entire refrigerated transport sector reached a substantial USD 17.45 billion in 2022. Although precise figures for the perishable segment are not available, it represents a considerable portion, supported by India's large agricultural output and the increasing demand for fresh produce. Major metropolitan areas such as Mumbai, Delhi NCR, Chennai and Bangalore, which are hubs of both consumption and agricultural production, have become key centres for reefer transport.

- **Growth drivers:** Several factors fuelling this upward trajectory.
- **Rising demand for perishables:** Rising disposable incomes, rapid urbanisation and a growing preference for healthier diets have significantly increased the demand for fresh fruits, vegetables, dairy products and meat. This surge necessitates efficient reefer transport to preserve the quality and freshness of these perishable goods.
- **Organised retail and e-commerce boom:** Simultaneously, the rapid expansion of organised retail and e-commerce, such as supermarkets, online grocery platforms, and quick-commerce models, has amplified the

need for robust cold chain logistics, with reefer transport as its cornerstone.

- **Government initiatives:** Programmes like the 'Scheme of Cold Chain, Value Addition and Preservation Infrastructure', are also playing a catalytic role by incentivising investments in cold chain infrastructure, including reefer transport and storage solutions.

Future market outlook:

- **Strong growth trajectory:** The Indian refrigerated transport market is projected to reach USD 26.74 billion by 2030, growing at a CAGR of 4.8% during 2023-2030. This growth is largely fuelled by the increasing demand for perishables.
- **Technological advancements:** The integration of IoT for real-time temperature monitoring and tracking, as well as data analytics for route optimisation, will play a significant role in improving efficiency and reducing wastage.
- **Sustainability focus:** There is a growing emphasis on adopting sustainable practices, such as transitioning to alternative fuels, utilising solar-powered reefer units, and optimising logistics to reduce the environmental impact.

Despite its immense potential, the market grapples with some persistent challenges. Inadequate cold storage facilities, particularly in rural areas, and limitations in road and power infrastructure present significant obstacles to maintaining a seamless cold chain. Fluctuating fuel prices, high maintenance costs for reefer units and import duties on equipment continue to impact the profitability of operators. Another critical bottleneck is the lack of skilled manpower. The shortage of trained drivers and technicians proficient in reefer unit operation and cold chain management practices hinders operational efficiency.

Energy efficiency measures in reefer transport for perishables in India

India's booming reefer transport sector faces a critical challenge: balancing the growing demand for perishables with the need for sustainable and energy-efficient solutions. The high energy consumption of traditional reefer

units, primarily reliant on diesel, raises concerns about environmental impact and operational costs. Fortunately, a wave of innovation and policy support is driving the adoption of energy efficiency measures throughout the cold chain.

Technological advancements:

- Improved reefer unit design and efficiency:
 - Optimised insulation: Newer reefer units utilise advanced insulation materials like Vacuum Insulated Panels (VIPs) that offer superior thermal performance compared to traditional polyurethane foam, minimising heat transfer and reducing energy consumption.
 - Efficient refrigeration systems: Improved compressor technology, variable speed drives and optimised refrigerant flow systems enhance the energy efficiency of reefer units.
 - Aerodynamic designs: Streamlined truck and trailer designs minimise drag, improving fuel efficiency and reducing emissions. This includes features like roof deflectors, side skirts and gap optimisation.
- Real-time temperature monitoring and control:
 - IoT-enabled sensors: Sensors monitor temperature, humidity and other critical parameters within the reefer unit, transmitting data in real-time to a central platform.
 - Remote monitoring and control: Operators can remotely monitor conditions, adjust temperature setpoints and receive alerts for deviations, enabling proactive intervention and minimising spoilage.
 - Data analytics for optimisation: Collected data undergoes analysis to optimise routes, improve driving behaviour, and identify opportunities for further energy savings.
- Alternative fuel technologies:
 - Transitioning from diesel: The sector is exploring alternative fuels like Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG) and biofuels as cleaner alternatives to diesel.

- Electric reefer units: Electric reefer trailers, powered by batteries or through connections to electric trucks, offer zero-emission transport, particularly suitable for urban deliveries and short-haul routes.
- Solar-powered reefer containers: Integrating solar panels into reefer containers supplements energy needs, reducing reliance on diesel generators and lowering emissions.

Operational best practices:

- Proper pre-cooling of cargo: Pre-cooling perishables to the desired temperature before loading significantly reduces the workload on the reefer unit during transport, which saves energy and maintains product quality.
- Efficient loading and stacking technique: Optimising cargo loading patterns ensuring proper air circulation within reefer unit maximises space utilisation improves temperature uniformity, thereby reducing energy waste.
- Cold chain management systems protocols: Implementing comprehensive cold chain management systems with real-time temperature monitoring, documentation and traceability enhances accountability, minimises the risk of temperature deviation and spoilage, which leads to energy savings.
- Driver training and awareness: Training drivers on eco-driving techniques, efficient reefer unit operation and cold chain practices can significantly contribute to energy savings and reduced emissions.

Government initiatives and policy support:

- Promoting cold chain infrastructure development: Government schemes, such as the Scheme of Cold Chain, Value Addition and Preservation Infrastructure, incentivise investments in modern, energy-efficient storage and reefer transport solutions.
- Fuel efficiency standards: Implementing stricter fuel efficiency standards for commercial vehicles, including reefers, encourages the adoption of more efficient technologies and practices.
- Financial incentives: Providing subsidies or tax breaks for investing in energy-efficient reefer units, alternative fuel technologies or cold chain infrastructure can accelerate adoption.

Challenges and opportunities:

- High upfront costs: The initial investment in energy-efficient technologies, like electric reefer units or solar-powered containers, can be a barrier for smaller operators.
- Lack of awareness: There's a need for greater awareness and knowledge sharing about the benefits and availability of energy-efficient solutions among stakeholders in the cold chain.
- Infrastructure gaps: Limited availability of charging infrastructure for electric reefer units and inadequate cold storage facilities in certain regions pose challenges.

Field observations on energy efficiency in refrigerated transport for perishables in India



Table 38: Energy efficient technologies in refrigerated transport

Measure	Vapor Compression Mechanism (VCM)	Phase Change Material (PCM) mechanism	Electric refrigeration
Fuel consumption	A 14FTx18FT container would roughly consume 2-2.5 litres of fuel per hour.	For the same size, up to 60-70% fuel savings can be observed in PCM-based chiller containers.	100% fuel savings, since the refrigeration system draws power from the truck's battery or an external power source.
Operation	Engine enables the operations of the refrigeration system.	A small charger mounted on the vehicle charges the PCM, which then keeps the container cool for up to 24 hours	The working principle is the same as a traditional VCM reefer vehicle, with the only difference being the source of power.

Results of fuel efficiency improvement in refrigerated transport

Though the study team interacted with and visited several reefer transports during field visits, the lack of data availability on energy consumption and potential for transition means that the study

does not explicitly account for the opportunities. The analysis presented below in Table 39 is based on the value judgement of the study team. It is recommended to define the data needs for this segment, collect the data and then identify the specific opportunities for energy transition.



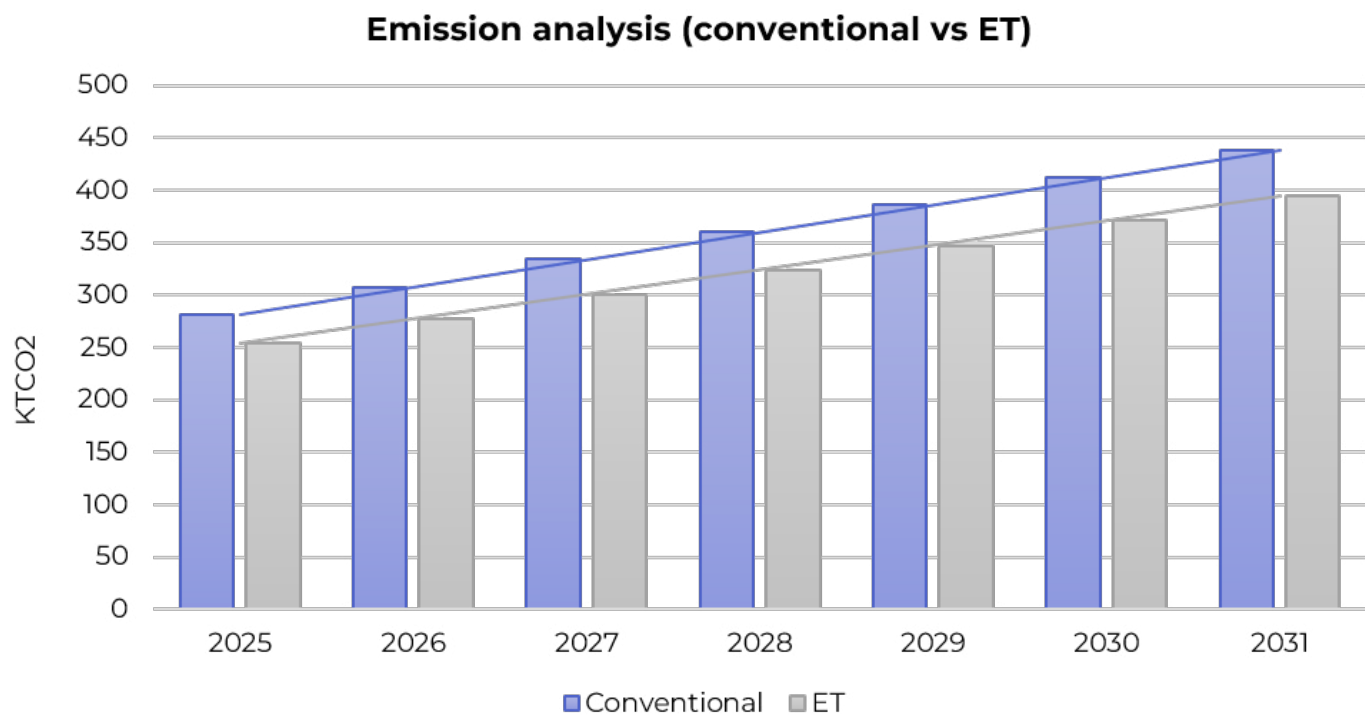
Table 39: Fuel efficiency in refrigerated transport

Measure	Unit	Conventional scenario 2031	ET 2031	Remarks
Fuel consumption	Million Litres	~165	~149	To model fuel consumption effectively, this study adopts a standardised approach. While refrigerated trucks vary in capacity, an average capacity of 10 MT is assumed for consistency and ease of analysis. This assumption aligns with typical truck capacities observed in the market and data found in relevant literature. Similarly, a fuel efficiency of 5 km/l is assumed based on industry averages and research findings. Under a conventional scenario, fuel consumption in the refrigerated transport sector is projected to increase by 42%, from 96.94 million litres in 2024 to 165.88 million litres in 2031. This significant rise is driven by the continued growth in demand for refrigerated transport and the corresponding increase in the number of vehicles on the road. However, as highlighted previously, technological advancements offer the potential to decouple this growth in the energy demand from a corresponding rise in emissions.
Emissions impact	ktCO ₂	~438	~394	To assess the potential impact of technological advancements, this study incorporates a 10% efficiency gain compared to the conventional scenario. This assumption is deliberately conservative, reflecting achievable improvements in areas such as refrigeration units, aerodynamics and tire technology within the projected timeframe. It is important to note that this estimate could be further enhanced by more aggressive adoption of emerging technologies like hybrid or electric refrigerated trucks.
Cumulative emissions impact	ktCO ₂	NA	~508	Furthermore, the projected efficiency gains from technological advancements are estimated to yield substantial environmental benefits. Between 2024 and 2031, these gains are anticipated to result in cumulative emission reductions of 507.86 ktCO₂, highlighting the significant potential of this sector to contribute to broader climate change mitigation efforts.

Figure 16 below shows the year-on-year emissions from the reefer vehicle segment in India, under the conventional and the ET scenarios. There is a cumulative emissions difference of 252 ktCO₂

under the conventional and the ET scenarios, contributing to approximately 10% emissions reduction.

Figure 16 Emission analysis in reefers (conventional vs ET)



Source: Author analysis

National-level energy transition

To effectively demonstrate the potential impact of a national-level energy transition within the cold chain sector, it's crucial to compare the current conventional scenario with the envisioned energy transition scenarios. This comparison highlights how adopting energy-efficient practices can lead to substantial improvements in both operational efficiency and environmental sustainability.

Table 40 below illustrates the energy consumption analysis across the two scenarios defined above. This comparison not only highlights the decreasing energy consumption per tonne of produce stored but also underscores the significant increase in energy usage derived from renewable sources. Additionally, there is a noteworthy reduction in energy consumption from grid electricity and diesel, reflecting a shift towards more sustainable practices.

Table 40: Total energy consumption analysis (conventional vs ET)

Cold chain component	Age categorisation	Conventional scenario (2031)		ET scenario (2031)	
		Total grid + diesel energy consumption (GWh)	RE energy consumption (GWh)	Total grid + diesel energy consumption (GWh)	RE energy consumption (GWh)
Packhouse		~10	~3	~9	~4
Cold storage (bulk)	>20 years	~1540	~358	~927	~401
	<=20 to 11=>	~230	~55	~150	~69
	<=10	~460	~109	~333	~160
Cold storage (hub)	>20 years	~420	~128	~292	~137
	<=20 to 11=>	~650	~196	~464	~220
	<=10	~240	~68	~183	~85
Ripening chamber		~3	~1	~2	~1
Reefer vehicle	-	~1,800	-	~1,597	-

Notes:

- The energy consumption per tonne (kWh/tonne) values for the conventional scenario has been derived from the data gathered through field visits.
- Based on the calculations, we considered an approximate savings percentage of 30% for bulk cold storages greater than 20 years old, 18% for bulk cold storages between 11 and 20 years old and 10% for bulk cold storages less than 10 years old. For hub cold storages, we considered a savings percentage of 20% for those greater than 20 years old, 15% for those between 11 and 20 years old and 10% for those less than 10 years old. Additionally, we considered a savings percentage of 10% for packhouses and ripening chambers in the energy transition scenario for the perishables value chain in India.

Following are the key insights that can be gathered from the energy consumption table above:

- Cold Storage (Bulk) and Cold Storage (Hub) facilities older than 20 years** consume significantly more energy compared to newer facilities in both scenarios. The oldest facilities have the highest energy consumption per tonne, highlighting the impact of ageing infrastructure on energy efficiency.
- Facilities older than 20 years in both Cold Storage (Bulk) and Cold Storage (Hub) categories have the highest energy consumption per tonne within their respective categories, pointing to potential inefficiencies and the use of outdated technologies in older infrastructure. This indicates that the maximum potential for energy transition lies in the cold storages which are greater than 20 years old.

- Energy use per tonne decreases in newer facilities (<=10 years)**, suggesting that modern facilities are more energy efficient.
- Modernisation of infrastructure:** Upgrading older facilities could significantly reduce energy consumption and improve efficiency.

Table 41 below provides a comprehensive overview of the transformative potential that the energy transition scenario holds for the cold chain sector by 2031. This comparison illustrates the substantial benefits of adopting energy-saving measures and renewable energy integration against the backdrop of the conventional operating scenario.

Table 41: Energy transition potential by 2031

Parameters	Unit	Conventional 2031	ET 2031
Annual energy demand	GWh	6,245	5,035
RE penetration (Conventional vs ET)	GWh	917	1,078
Total annual energy savings through ESMs	GWh	NA	876
Total annual emissions without reefers (Conventional vs ET)	ktCO ₂	2,150	1,409
Total annual emissions - reefers (Conventional vs ET)	ktCO ₂	438	394
Total annual emissions impact (conventional vs ET)	ktCO ₂	NA	785

Notes:

- Methodological differences in energy consumption projections: This study's energy consumption projections differ from those in the Indian Cooling Action Plan (ICAP) due to methodological variations. While this study grounds its estimates in current cold chain sector market behaviour, drawing from direct field observations and online consultations, ICAP forecasts energy consumption based on anticipated demand trends.
- This analysis focuses on implementing ESMs specifically within cold storages, packhouses and ripening chambers, and a 10% fuel efficiency for reefer vehicles.
- Field observations indicate that RMS installations are feasible only for packhouses and ripening chambers.
- Assumptions for cost and emission calculations: This analysis assumes a solar photovoltaic (PV) cost of INR 50,000 per kW for investment estimations. Emission savings are calculated using a grid emission factor of 0.757 tCO₂ per MWh (CEA, 2024) and a diesel emission factor of 2.64 kg CO₂ per litre (Deepak Baidur, 2022).

Energy transition outlook

Annual energy demand (GWh): This parameter reflects the total energy consumption within the cold chain sector. Under the conventional scenario, the demand is projected to reach 6,245 GWh by 2031. However, with the implementation of energy transition measures, this demand can be reduced

by 1,210 GWh, bringing it down to 5,035 GWh. This represents a significant improvement in energy efficiency across the sector.

RE penetration (GWh): A critical component of the energy transition scenario is increasing the contribution of renewable energy. The analysis shows a rise from 917 GWh in the conventional scenario to 1,078 GWh in the energy transition scenario. This shift not only reduces dependency on non-renewable sources but also reflects a commitment to sustainable energy practices.

Total annual energy savings through ESMs (GWh): Under the energy transition scenario, the implementation of advanced energy-saving technologies and practices yields annual energy savings of 876 GWh. This demonstrates the effectiveness of these measures in significantly lowering the energy consumption across cold chain operations.

Total annual emissions without reefers (ktCO₂): By adopting energy-efficient practices, the sector can achieve substantial reductions in greenhouse gas emissions. Emissions drop from 2,150 ktCO₂ in the conventional scenario to 1,409 ktCO₂ in the energy transition scenario, highlighting the environmental benefits of transitioning to cleaner technologies.

Total annual emissions—reefers (ktCO₂): Even within reefer transport, emissions can be decreased from 438 ktCO₂ to 394 ktCO₂. This reduction indicates the potential benefits of integrating energy-efficient technologies and practices in mobile infrastructure as well.

Total annual emissions impact (Conventional vs. ET) (ktCO₂): The cumulative emissions reduction achieved by transitioning to energy-efficient scenarios is reflected in a total impact of 785 ktCO₂. This significant reduction underscores the potential of the cold chain sector to contribute to national emission reduction targets.

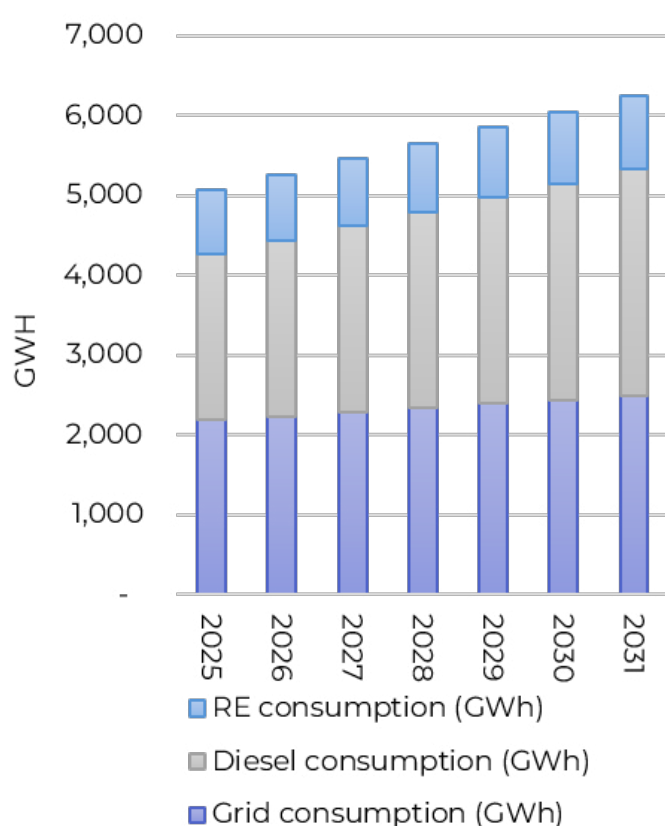
The ET scenario emphasises a greater adoption of renewable energy, particularly solar energy, alongside energy-saving measures. As a result of these interventions, energy consumption from the grid and diesel usage are projected to decrease. In the ET scenario, the uptake of renewable energy for cold chain infrastructure increases to 40%. This is a significant rise from the current levels, which range from 20-30% for cold storages and packhouses,

and less than 10% for ripening chambers. Table 42 below shows the energy consumption split for the conventional and ET scenarios. It illustrates an increased share of renewable energy in the total energy consumption, thereby reducing dependency on the grid and diesel generators. The ET scenario projects an approximate reduction of 30% in diesel consumption and a 35% reduction in energy consumption from the grid.

In the conventional scenario, energy consumption in the cold chain is expected to increase from 4,872 GWh in 2024 to 6,245 GWh by 2031. However, under the ET scenario, energy consumption in 2031 is projected to reach 5,035 GWh. This represents a 19% reduction compared to the conventional scenario.

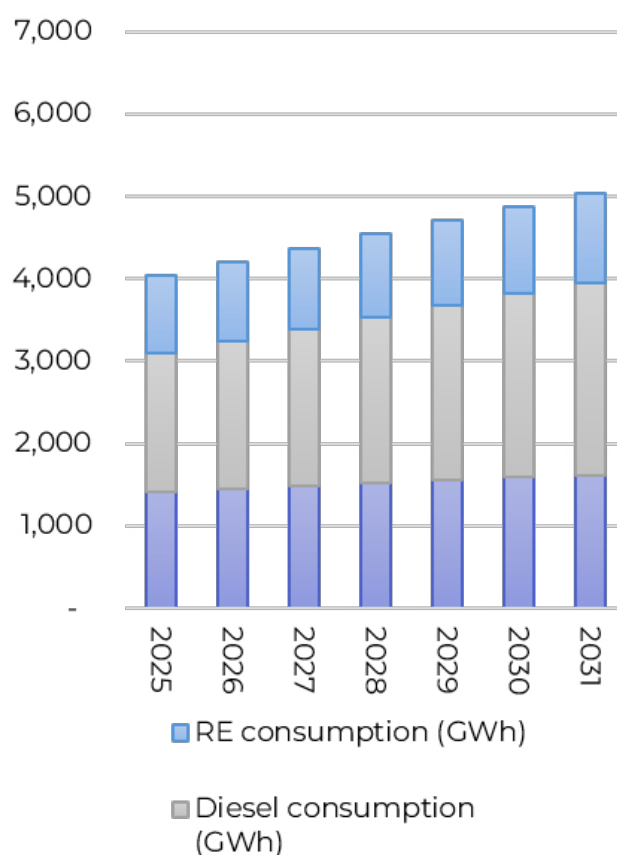
Figure 16: Emission analysis in reefers (conventional vs ET)

Conventional scenario



Source: Author analysis

ET scenario



Source: Author analysis

Emissions outlook under the energy transition scenario

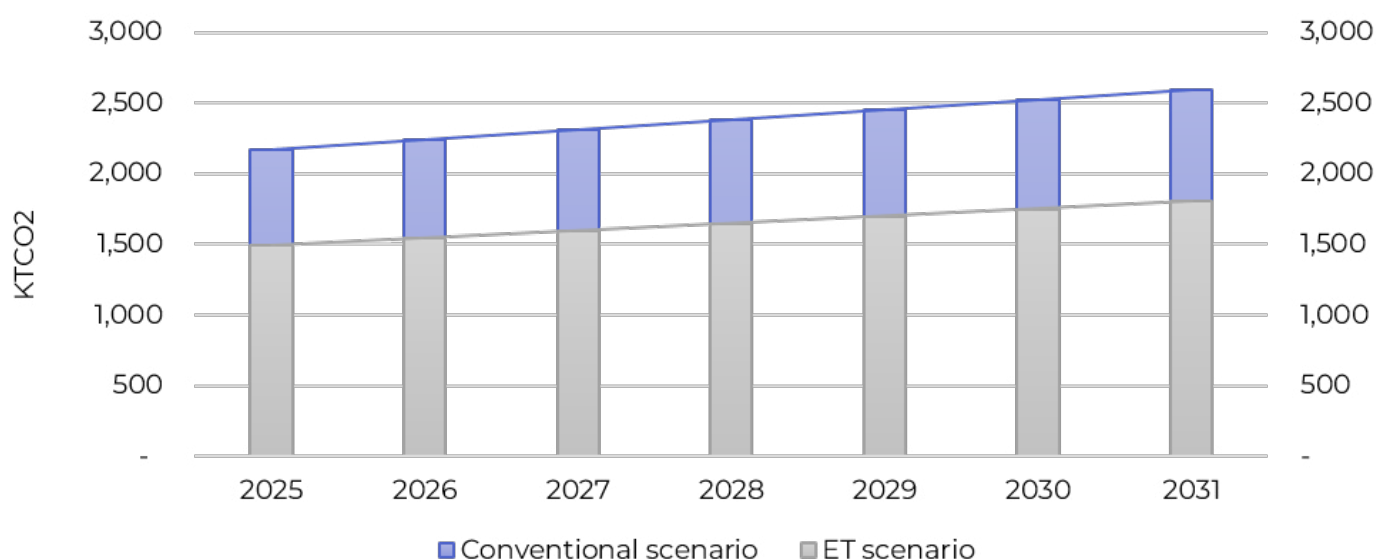
This section presents the analysis of the GHG emissions in terms of kilo tCO₂ for the total emissions from energy consumption in the CCI. Figure 17 below provides the trend in total emissions from CCI under conventional versus ET scenarios.

- The consequent emissions resulting from growth in energy consumption in the conventional scenario are projected to reach 2,588 ktCO₂ in 2031.
- Under the ET scenario, the overall

emissions trajectory reduces through the implementation of ESMs and accelerated RE adoption. Compared to conventional scenario, the total GHG emissions in 2031 would reduce by 785 ktCO₂.

- Implementation of ESMs under ET scenario would yield a reduction of 663 ktCO₂ in 2031. Furthermore, the cumulative emission reduction achieved will be 4,357 ktCO₂ between now and 2031.
- Under the ET scenario, the implementation of aggressive ECMs and accelerated RE adoption helps slow the growth of emissions.

Figure 17: Trend in annual emissions under conventional vs ET scenario



Source: Author analysis

Impact on energy consumption and demand reduction

- Two key elements are crucial for energy transition: Energy efficiency and renewable energy adoption. Improving energy efficiency reduces the need for additional capacity, saving capital investment. Off-grid renewable energy solutions can enhance power availability in areas with limited supply.
- Implementing energy efficiency measures in existing infrastructure can reduce energy demand by approximately 1,057 GWh in 2031, or nearly 22%, compared to the 2031 conventional scenario. Potato storage facilities represent a significant portion (75%) of the

facilities where these improvements can be made.

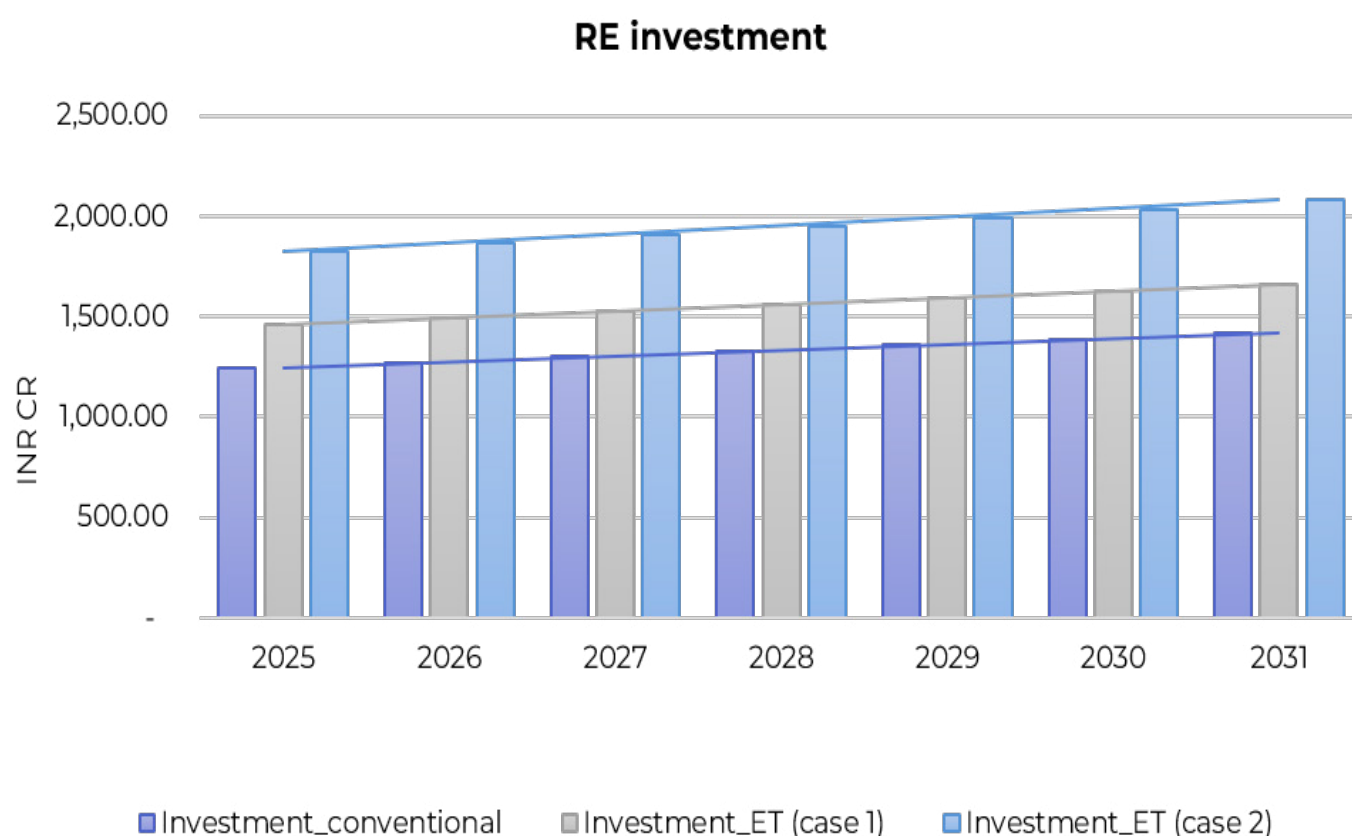
- Rooftop solar offers a key solution for decarbonising the energy supply. There is potential to increase renewable energy consumption by 160 GWh beyond current projections under the conventional scenario, according to the ET scenario.
- The identified investment potential for ESMs in the specified states comprises INR 1135cr for the potato assessed states (Uttar Pradesh and Gujarat) and INR 77cr for the chilli state (Andhra Pradesh). Considering the overall national level investment required for the potato cold chain infrastructure (ESM Considering the overall national-level

investment required for the potato cold chain infrastructure, including ESM and solar PV, it is approximately INR 3,000 crore.

- Accelerating the adoption of renewable energy will require incremental investments of INR 1,622cr for the ET scenario over the conventional scenario from 2025 till 2031. This investment potential represents only the incremental investment difference between the conventional and ET scenarios. Figure 18 below illustrates the investment potential for different renewable energy penetration

percentages. As stated in the ET scenario definition above (case 1), the renewable energy penetration cap was assumed to be 30% for packhouses and ripening chambers, and 40% for bulk and hub cold storages. If an aggressive approach (case 2) is considered, with 40% penetration for packhouses and ripening chambers and 50% penetration for bulk and hub cold storages, the investment increases further.

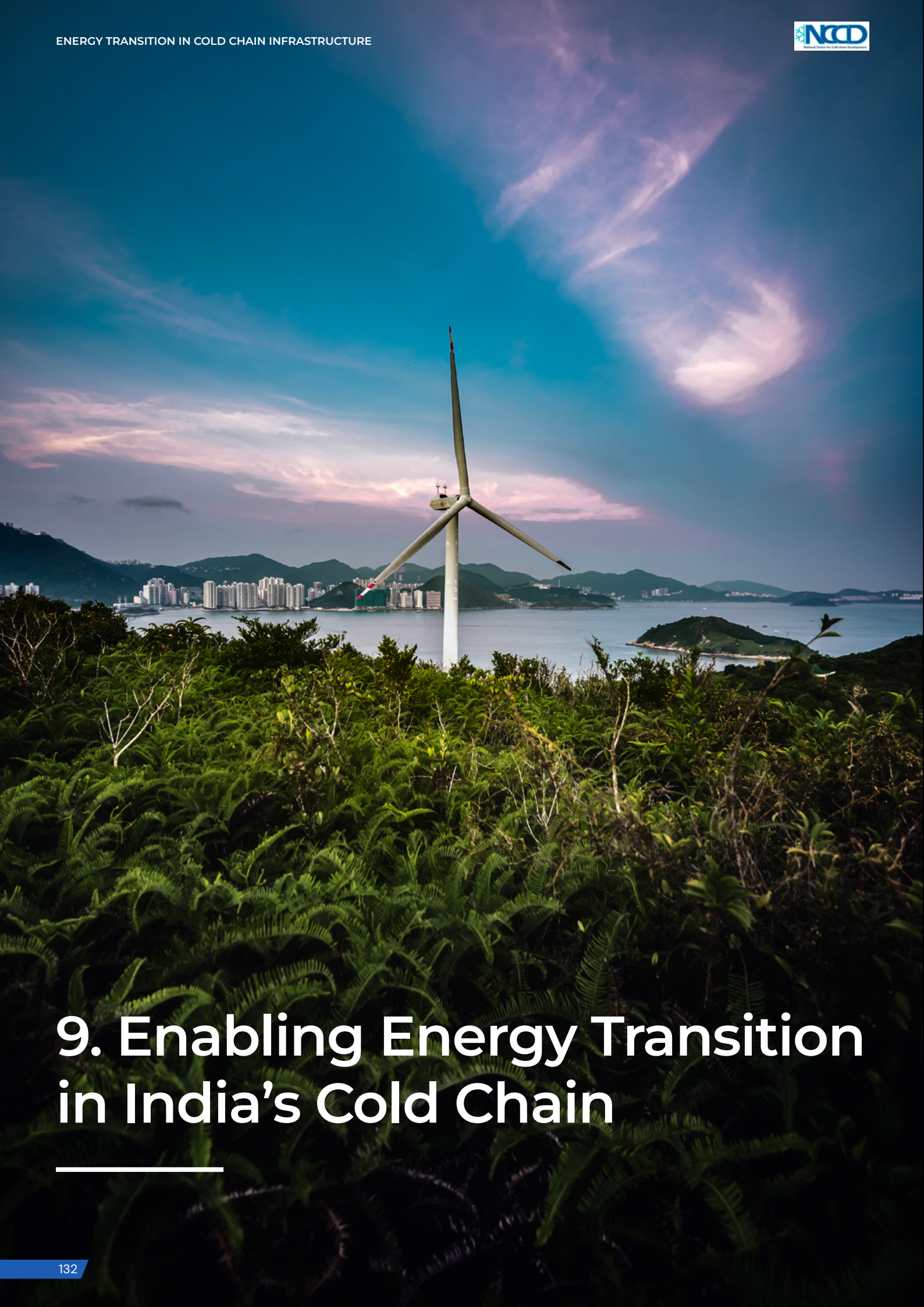
Figure 18 RE investment (conventional vs ET)



Source: Author analysis

Observation

- An urgent efficiency gap concentrated in ageing bulk and hub cold storages and in reefer transport. This is driven by high retrofit costs (especially compressors and insulation), unstable power that forces diesel generator use, costly and scarce low GWP refrigerants with safety and compatibility constraints, limited O&M standardization, low scheme awareness and skills shortages, and tight financing.
- A practical 2025–2031 pathway centres on four levers—reducing demand (e.g., switching EPS to PUF), improving efficiency (BLDC fans, IE3 motors, higher efficiency open type compressors, LPR on ammonia systems, remote monitoring), integrating renewables (notably rooftop solar at farmgate and hubs), and a cautious refrigerant transition—yielding the biggest gains in facilities over 20 years old, especially potato storages.
- Under the energy transition scenario, total energy demand in 2031 drops to about 5,035 GWh (vs 6,245 GWh in a conventional path), renewable use rises to roughly 1,078 GWh, efficiency measures save about 876 GWh annually, and emissions fall by around 785 ktCO₂, alongside lower reliance on grid power and diesel.
- Solar cold rooms are spreading at the farmgate, hub level PV can cut grid draw by roughly 30–50%, and chilli storages offer smaller but meaningful savings, while grape assets are too dynamic for firm quantification.



9. Enabling Energy Transition in India's Cold Chain

This chapter presents the way forward derived from the research and analysis within the report, structured to support a phased and sustainable energy transition in India's cold chain sector. The recommendations are divided into two main horizons: Way forward for 2025-2031 and way forward for 2032 and beyond, facilitating clear pathways towards greater efficiency and sustainability.

To effectively address the unique challenges across the sector, the recommendations are further categorized based on the nature of the infrastructure:

- **Existing Infrastructure:** Focused on upgrading and transitioning the current bulk cold storage facilities, particularly older infrastructure where significant energy savings and emission reductions can be realized.
- **Upcoming Infrastructure:** Targeted at newly developed facilities, encouraging alignment with the latest NCCD's engineering guidelines and minimum standards 2025.

Way forward for 2025-2031, emphasizes overcoming barriers such as fragmented supply chains, high capital costs, and limited awareness of available support mechanisms. Strategic planning at the national level, including mapping of perishable production and consumption regions—will guide infrastructure development and optimization efforts. These suggestions address key areas including policy reforms, supply chain and infrastructure improvements, training and capacity building, with an overarching goal to make the infrastructure energy efficient, reduce post-harvest losses and accelerate renewable energy adoption.

Way forward for 2032 and beyond prioritizes the integration of advanced technologies, digital solutions, and international collaboration, positioning India's cold chain sector to meet global standards in efficiency, sustainability, and innovation.

9.1. Way Forward - (2025-2031)

A. Existing Cold Chain Infrastructure

Policy & Regulatory:

- a) Study identified that over 70% of bulk cold storage facilities in key states like Uttar Pradesh and West Bengal are over 20 years old and rely on energy-intensive ammonia bunker refrigeration systems. This provides an opportunity to evaluate the existing systems and retrofit them to ammonia unitary systems to align with the NCCDs EG&MSS and enable the use of available government support and incentives.

Way Forward

Assess the possibility of establishing a national, time-bound modernization and retrofit program for aging cold storages, phased by priority states. It could begin with state-level pilot retrofits to generate demonstrable case studies and build awareness, thereafter scale up further

with regulatory linkage (such as to NCCDs EG&MSS) to ensure consistent adoption and streamlined implementation.

- b) Facilities install a wide mix of equipment. Older bulk storage (especially Type 1 potato units) often run on bunker-coil systems, IE1 motors, and legacy controls, while newer ones are freon based on ammonia unitary systems with efficient motors, among others. Insulation varies from efficient PUF/PIR to thermocol, rice husk, or glass wool across regions and facilities. This inconsistency drives higher kWh per tonne handled and operating costs.

Way Forward

Evaluate introducing a national framework that sets minimum performance benchmarks for major cold-chain equipment in addition to the existing NCCDs EG&MSS which

standardizes/defines other components within storage or transportation facilities, and drive phased replacement of inefficient assets and ensures environmentally responsible end-of-life practices, supported by a compliance mechanism to anchor uptake.

Training, Skill Development, and Capacity Building

- a) The assessment identifies a lack of standardized O&M practices and formal training for the existing workforce, which hinders the optimal performance of existing refrigeration system and slows the adoption of energy-efficient retrofits.

Way Forward

Consider initiating a sector-wide capacity-building and certification initiative to elevate technician and operator competencies in energy efficient operations and retrofitting, delivered through practical, industry linked training to drive consistent performance improvements across existing cold chain assets.

- b) The report highlights a significant awareness gap among facility owners regarding the benefits of modernization and the availability of financial assistance schemes, which creates inertia against investment in upgrades.

Way Forward

An opportunity exists to develop a nationwide awareness and outreach initiative to create and disseminate accessible, multilingual content (brochures, videos, webinars) explaining the technical benefits, energy savings, and return on investment from energy efficiency measures. The existing agricultural extension networks like Krishi Vigyan Kendras (KVKs) and State Horticulture Departments may be utilized to conduct awareness drives. Further, workshops that simplify the understanding and application processes for central and state-level subsidy schemes, including the establishment of local “help desks can be explored.

Infrastructure & Supply Chain

- a) The report identifies that a majority of bulk cold storage infrastructures are concentrated at the mid/hub level, disconnected from the farm gate. This creates a critical bottleneck, leading to energy wastage and post-harvest losses before produce even enters the main cold chain.

Way Forward

There may be merit in moving to a national, data led planning approach that aligns cold chain capacity with production and demand patterns. Further, a hub and spoke configuration in which multi commodity hubs are connected to farm gate pre cooling and aggregation nodes can be explored. This could help target infrastructure strengthening, improve utilization of existing assets, and enhance end to end flow of perishables. In new NCCD guidelines efforts have been made to integrate supply chain and reduce post-harvest losses at Farm gate.

- b) The report highlights the existing reefer transport fleet is unorganized, lacks digitisation and are significant energy consumers mainly due to inefficient operations.

Way Forward

There is an opportunity to build confidence in reefer digitization by demonstrating measurable energy and cost benefits versus current practices, and by sharing credible, India-specific case examples through relevant government portals such as MoAFW, NCCD, MoRTH, others to catalyze wider adoption.

B. Upcoming Cold Chain Infrastructure

Policy & Regulatory

- a) All new cold chain infrastructure in the country must be designed to meet the current guidelines and energy efficiency standards from the beginning. Doing so will help in avoiding investment in inefficient infrastructure.

Way Forward

Consider a national approach that ties project approvals and public support to EG&MSS 2025 alignment, while setting minimum efficiency thresholds for equipment under an expanded BEE Standards & Labelling framework—thereby driving sector-wide performance.

- b) The report identifies India's cold chain as fragmented and low on operational visibility, causing preventable losses, misaligned capacity, and higher costs. Limited data on locations, capacities, and usage impedes coordination of storage and reefer assets. Absence of uniform data capture and dashboards further hampers planning, scheme governance, and performance tracking across states and asset types.

Way Forward

A unified national digital backbone that provides live visibility into asset locations, capacities, utilization, and key performance parameters (e.g., temperature and energy) can be the key. This common platform should enable consistent data capture and dashboards across storage and transport to improve planning, operations, and accountability. NCCD is already undertaking numerous initiatives in this direction with an aim of digitizing the overall sector for an informed growth and development.

- c) An efficient cold chain requires more than just isolated storage points; it needs a seamless, end-to-end logistics network. Over-reliance on road transport for long hauls is economically and environmentally inefficient.

Way Forwards

There lies a significant potential of advancing multimodal cold-chain logistics through a phased approach: assess feasibility to identify viable infrastructure options, then mainstream adoption by aligning them with existing policies, schemes, and incentives under a streamlined policy framework.

Training, Skill Development, and Capacity Building

- a) For new facilities to incorporate advanced refrigeration technologies and also explore options like solar PV, low-GWP refrigerants, and IoT, the current technical training landscape is inadequate. A new generation of skilled professionals is required to manage this modern infrastructure.

Way Forward

Promote the development of nationally recognized certification programs for cold chain professionals to ensure a benchmark of quality and expertise, collaborating technical training institutes and focusing on solar PV system maintenance, safe handling of natural and low-GWP refrigerants, and digital monitoring systems.

3. Infrastructure & Supply Chain

- a) To prevent the proliferation of standalone, inefficient units, new infrastructure must be planned and developed as part of a larger, integrated system. The report highlights the need to move from isolated storage points to a seamless, end-to-end network.

Way Forward

There seems a potential for an Integrated Cold Chain Development Program that funds regional multi-commodity hubs linked to standardized farm-gate pre-cooling and aggregation collection points, with all assets required to be certified to NCCD 2025 engineering guidelines. This will deliver interoperable, energy-efficient, and seamlessly integrated supply chains across all government-supported projects.

9.2. Way Forward – 2032 and beyond

1. National cold chain rail connectivity program

The report underscores the over-reliance on road transport and a potential of exploring multi modal transport – one such opportunity could be utilizing India's extensive railway network for refrigerated goods. A modal shift is critical for long-term sustainability and efficiency.

Way Forward

An opportunity exists to position rail as the backbone for long distance refrigerated movement within an integrated multimodal cold chain, learning from successful international examples to drive decarbonization, cost efficiency, and reliability. A national initiative to evaluate refrigerated logistics corridor that leverages Indian Railways for long-haul movement of perishables, anchored by a high-level, multi-stakeholder feasibility study and informed by collaboration with international leaders such as the EU's CoolRail. In parallel, establish an enabling policy and incentive framework to drive multimodal shifts from road to rail in cold-chain logistics, with the dual goals of reducing emissions and lowering total logistics costs while improving reliability and

2. Refrigerant transition within the cold chain sector

India's cold chain sector relies heavily on high-GWP refrigerants, contributing to rising emissions and long-term environmental risks. Transitioning to low-GWP alternatives such as HFOs and natural refrigerants (e.g., HFO's, R-290, R-600a, liquid CO₂) is essential to align with climate goals, reduce operational costs, and future-proof infrastructure.

Way Forward

Going forward, there is a potential to launch a coordinated national program to accelerate adoption of low-GWP refrigerant technologies in the cold chain by combining targeted field pilots in high-density horticulture clusters to validate performance, safety, and efficiency; comprehensive technician upskilling on installation, maintenance, and safe handling; and a multilingual awareness drive for MSMEs, FPOs, and cold chain operators to build market confidence and enable rapid, safe scale-up of the low GWP alternatives in the sector. This will also help the sector align with India's broader environmental commitments in the various international forums, such as the Kigali amendment.

3. Integration of Cold Chain Infrastructure into Mega Food Parks

Integrating cold chain infrastructure into mega food parks is a strategic move to strengthen India's agro-processing capabilities, reduce post-harvest losses, and enhance value addition.

Way Forward

There is scope to progress toward integrated, farm to market cold chain corridors anchored within food parks—linking farmgate aggregation and pre cooling, processing, storage, and last mile distribution—to reduce losses and preserve quality. Planning and implementation could align with NCCD's EG&MSS 2025 and relevant PMKSY components to ensure consistency with national standards, streamline approvals, and enable coordinated financing and data interoperability across the network.



10. Appendices

10.1. List of stakeholders consulted

Stakeholder	Type	No. of consultations	Discussion topics
Bluestar, Danfoss, Carrier Transicold, Tessel, Thermax	Technology provider	5	EE technologies, refrigerants, RoI on modernisation, new setup and reefers
Uttar Pradesh, Maharashtra, West Bengal	Cold storage associations	3	Cold chain landscape in the state, challenges faced and way forward
Federation of Cold Storage Association of India (FCAOI), ISHRAE, Gujarat Chamber of Commerce and Industry (GCCII), Maharashtra Cold Storage Association (MCSA), West Bengal Cold Storage Association (WBCSA)	Federation	11	General understanding of the sector, related policies, challenges and way forward
Mr R K Jain, Mr Virendra Gheware	Chartered accountant	2	Available schemes or subsidies, availing process, challenges in availing the subsidies and way forward
West Bengal, Andhra, Punjab	State horticulture department	3	Cold chain landscape in the state, challenges faced and way forward
ACR consultants	Cold chain consultant	1	Efficient cold storage infrastructure and best practices
Grun Power, TATA power, Dhruva Engineering	Renewable energy providers	6	RE integration feasibility, RoI, financing, net metering and net billing
Kingspan Jindal, A star, SPL	Insulation providers	3	Insulation used in current infrastructure, R, K and U values and way forward
NSSPL	Turnkey solution provider	1	Infrastructure development, technologies and automation

10.2. List of studies on cold chain

No.	Study name	Year	Scope of the study
1	All India Cold Chain Infrastructure Capacity Assessment of Status and Gap	2015	The study had assessed the CCI market and came up with significant figures regarding existing CCI infrastructure. Based on the inventory, it also analysed the actual requirement and the infrastructure gap across India as of 2014.
2	Establishments of Cold Storage Unit for Fresh Onion	2017	The report has assessed the market of cold storages in India and analysed the growth of the Indian cold chain industry for the period of 2009 to 2017. Further, the research had done a deep dive into the potential of onion cold storage in the state of Gujarat, including their key advantages such as favourable policies of the state government. It has also explored the existing dedicated policy incentives for the uptake of onion cold storages in Gujarat.
3	Promoting Clean and Energy Efficient Cold-Chain in India	2019	The report evaluates the state of clean cold chain practices in India, assessing existing technologies, energy consumption, incorporation of renewable energy sources and the Global Warming Potential (GWP) of refrigerants. By combining insights on policy, finance and technological advancements, the report aims to offer compelling evidence and suggestions for progressive cold chain sector in India. Four states were studied to develop the roadmap for sustainable cold chain in India.
4	Cold Chain Energy Efficiency in India: Analysis of Energy Efficiency Opportunities in Packhouses	2021	The main objective of the study was to support BEE in developing policy and regulatory strategies to enhance energy efficiency in packhouses across India. The study had analysed the potential of energy efficiency interventions in the existing packhouses in India and carried out a comprehensive analysis of 21 packhouses across different agro-climatic zones of the country by conducting field visits to six states.
5	India Cooling Action Plan: Operationalising Cold-Chain Recommendations	2021	The ICAP and MoEFCC have decided to include six thematic working groups to operationalise the recommendations in which cold chain and refrigeration is one among them. The report has identified that the proposed recommendation can bring savings in energy consumption in the cold chain up to 11%. It has also provided the action points to be followed for the better management of cold chain infrastructure to reduce energy consumption.
6	Analysis of Potato Value Chain in West Bengal: Roadmap for Modernisation of Cold Storages	2021	The report has assessed the status of potato cold storages in the state of West Bengal (WB). It has analysed the supply chain of potato in WB and the cold storage landscape for the perishable. Detailed energy audits were carried out for three types of cold storage infrastructure in the Hooghly district for comprehensive analysis. In addition, the study has assessed the Standardised Energy Efficiency Measures (EEMs) and proposed along with the cost-benefit analysis of the EEMs.

No.	Study name	Year	Scope of the study
7	Investment opportunity in climate friendly and energy efficient Cold Chain	2022	The report has explored investment opportunities in the cold chain sector in India, keeping the key focus on packhouses and reefer transport. The investment potential has been evaluated based on the market assessment done by NCCD in 2015. The analysis also delves into the key barriers for the growth of the components and innovative business models that can catalyse the investments.
8	Making Sustainable Cooling in India Affordable	2022	The report explores the pathways for enhancing access to sustainable cooling sector in India including cold chain. The key barriers for the increased adoption of sustainable technologies for cold chain include high cost which are not addressed, lack of awareness regarding the value addition with sustainable technologies, concerns about safety measures and reduced investments in sustainability. A comprehensive analysis of business models for sustainable cooling has been carried out as well, with case studies. Additionally, the report has provided recommendations for the increased uptake.
9	Climate Investment Opportunities in India's Cooling Sector	2022	The report delved into four key areas of cooling sector in India which were space cooling, cold chain and refrigeration, passenger transport, and air conditioning and refrigerants. Two key areas of opportunities have been identified and analysed in the study which are development of new energy efficient sustainable CCI and energy efficiency interventions and clean energy integration in the existing facilities, where the former has been prioritised in the study due to the implementation challenges for the latter.
10	Assessment of the Cold Chain Market in India	2023	The research aimed to identify the existing cold chain technologies, business models and technical obstacles, as well as assess the existing cold chain infrastructure and potential areas for improvement. The study analysed the CCI market by components and evaluated the market gap as of 2020. The value chain analysis has covered the ecosystems that include, fruits and vegetables, fish, meat and dairy. The report also covered evaluation of national cold chain policies, estimation of off-grid solar refrigeration technologies and the development of case studies that explore the innovative business models for off-grid systems.
11	Greening Cold Chain Infrastructure to Develop Global Food Corridors: Accelerating the Achievement of the 2030 Agenda	2023	The study shed some light on the significance of sustainable cold chain infrastructure in India; as India's production potential is high and there are notable post-harvest losses. The report also explores how the world will benefit if the G20 takes collaborative initiatives and efforts towards the building of sustainable cold chains.
12	All India Survey and Gap Analysis of Cold Storage and other Cold Chain Components – Revision of the 2015 report	On-going	NCCD has instituted a study to revise the assessment of cold chain infrastructure. The study will include assessment of current infrastructure at a national level, demand analysis and evaluation of the existing gap of all the cold chain infrastructure components.

10.3. Case Example

Case example – Cold chain innovations in Allana Group

Problem statement:

The Allana group, a prominent player in the Indian food processing and export industry, faced significant challenges in maintaining the quality and shelf life of perishable goods due to inefficiencies in their cold chain operations. Traditional refrigeration methods and infrastructure were insufficient to meet the demands of modern food logistics, leading to increased energy consumption and operational costs. Additionally, the lack of sustainable practices in their operations contributed to a higher carbon footprint, which was not aligned with the company's sustainability goals. These challenges not only threatened product quality and customer satisfaction but also limited the group's ability to expand into more distant export markets where stringent temperature control is crucial.

Implementation:

In response, the Allana Group embarked on a comprehensive overhaul of their cold chain facilities, integrating state-of-the-art technologies and sustainable practices. They adopted modern refrigeration systems featuring variable frequency drives (VFDs) and energy-efficient compressors, which dynamically adjust to real-time cooling demands, significantly optimising energy consumption. The infrastructure was revamped using high-quality insulation materials and innovative building designs to minimise heat exchange, ensuring consistent storage temperatures with reduced energy use. In pursuit of sustainability, the company installed solar panels to power their operations, reducing dependence on conventional energy sources and lowering their carbon footprint. LED lighting and advanced energy management systems were implemented, facilitating real-time optimisation of energy use. Furthermore, HVAC systems were enhanced with smart controls, and transportation logistics were optimised using route management software and energy-efficient vehicles, reducing both fuel consumption and emissions.

Outcome:

The integration of these innovations has markedly improved Allana group's cold chain operations. Precise temperature control has enhanced the shelf life and quality of perishables like meat and dairy products, minimising spoilage and boosting customer satisfaction. The efficient logistics and refrigeration capabilities have enabled the company to expand their export reach, particularly in the Middle East, Southeast Asia and Africa, where their meat products have gained a reputation for consistent quality. Their robust cold chain system has also facilitated the distribution of dairy products to remote areas, ensuring product freshness and safety upon arrival. Operational costs have been reduced through energy-efficient technologies and optimised logistics, leading to substantial savings in energy and fuel expenses. These advancements have also fostered strategic partnerships with retailers and food manufacturers, leveraging the company's expertise for broader distribution networks. Collectively, these efforts have solidified the company's position as a leader in cold chain management, setting a benchmark for energy efficiency, product quality, and market expansion in India's cold chain industry.

Case example – Solar PV installation at Sree Sairam Cold Storage in Inkollu, Andhra

Problem statement:

Sree Sairam Cold Storage, located in Inkollu District, Andhra, was established in 2020. However, due to financial constraints during the construction phase, the owner did not install solar PV panels on the rooftop. Over the first three years of operation, the facility experienced 100% utilisation, leading to a heavy reliance on the grid for electricity, which resulted in higher monthly electricity bills.

Implementation:

To address this issue, the facility owner hired Dhruva Engineering, a renowned local solar contractor, to install solar PV panels on the rooftop. The contractor installed a 120-kW solar PV system, which covered 90% of the facility's maximum load. The installation was completed in November 2024.

Outcome:

After the installation, the owner observed a significant reduction in monthly electricity bills. For example, the electricity bill for January 2024 was INR 1,44,992, and consumption was 11,673 kWh from the grid. In contrast, the bill for January 2025 was INR 1,02,935, and grid consumption was 6,468 kWh. The solar PV system generated an additional 3,909 kWh. The comparison between the bills for January 2024 and 2025 takes into account similar climatic conditions. The relatively cooler month of January generated 3,909 kWh of solar electricity, which is expected to increase significantly during the summer months. The owner states that the payback period for solar installation is four years.

Case example – Transcritical CO₂ systems in Turkey (moving towards low GWP refrigerants)

Problem statement:

The Carrefour Group faced a significant challenge in their Istanbul hypermarket. They needed to replace the conventional R-404A multiplex rack system with a more sustainable solution. The group aimed to eliminate the use of HFC refrigerants, reduce system leaks and improve energy efficiency. This undertaking was complicated by several factors, including high operating pressures and the necessity for advanced design solutions tailored to hot climates. Furthermore, the scarcity of qualified service contractors and limited expertise for service and maintenance in Istanbul added to the complexity of the project.

Implementation:

In response to these challenges, Carrefour Group implemented the first trans-critical CO₂ system in Turkey in 2012, marking a significant milestone in refrigeration technology within the region. The system was equipped with steel pipes designed to withstand high operating pressures. To address the specific demands of the hot climate, an adiabatic air-cooling system was integrated into the design. Additionally, the system was engineered to reduce the number of brazed joints, effectively minimising potential refrigerant leaks and enhancing the system's overall reliability.

Outcome:

The outcome of this innovative implementation was highly successful. The trans-critical CO₂ system delivered cooling performance comparable to traditional R-404A systems operating under similar climatic conditions. Notably, the project successfully eliminated HFC refrigerants from the hypermarket's refrigeration system. The design improvements led to a 75% reduction in refrigerant leaks, while energy efficiency saw a significant boost of approximately 15%. However, the project also underscored the pressing need for more qualified service contractors and expertise in the CO₂ refrigeration market to support such advanced systems.

10.4. Additional details on business models

Cooling-as-a-Service

A key factor in making farmgate cold chain infrastructure accessible is a focus on energy transition. Small and marginal farmers, alongside other supply chain stakeholders, will only adopt cold chain solutions if they are affordable within their local economic context. Moreover, simply providing equipment or infrastructure is insufficient. Sustainable interventions require appropriate business models, efficient cold chain management systems, and comprehensive training and skill development.

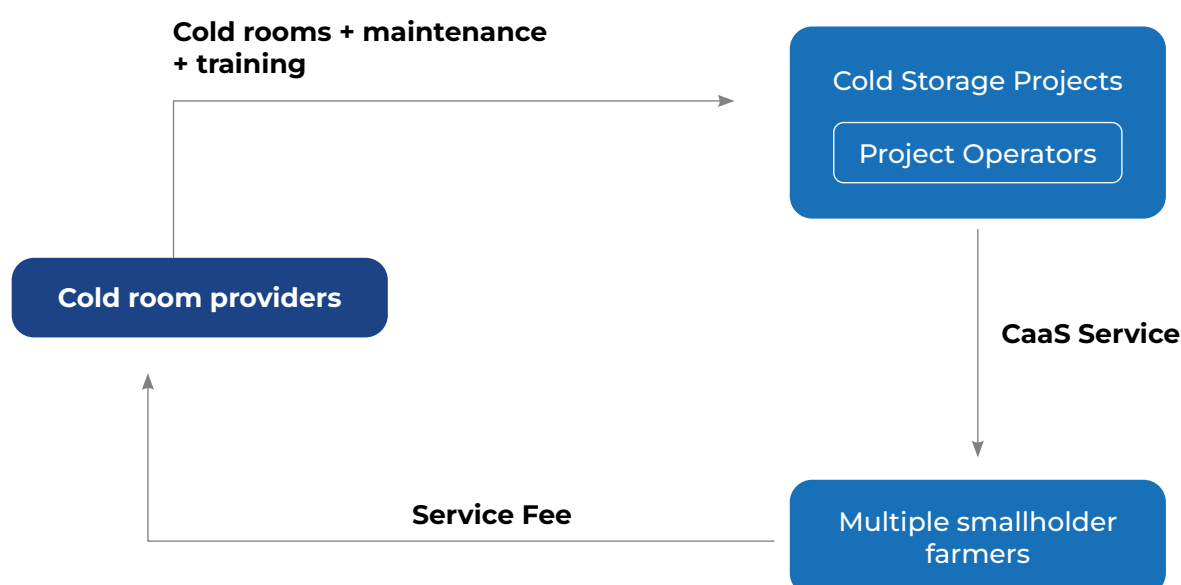
One highly effective model suitable for nationwide implementation at the farmgate level is Cooling as a Service (CaaS). Observed during site visits in parts of Andhra and Maharashtra, this 'pay-as-you-use' approach, primarily implemented through FPOs, deserves wider adoption. Essentially a cold storage 'on-demand' model, CaaS is particularly beneficial for small farmers and those at the first mile of connectivity who require cooling access but have limited purchasing power.

CaaS offer several benefits:

- **Reduced upfront costs:** Customers don't have to invest heavily in equipment, making it easier to adopt energy-efficient technologies.
- **Predictable costs:** Customers pay a fixed fee for the service, regardless of energy consumption fluctuations.
- **Incentive for efficiency:** Providers are incentivised to optimise energy usage to maximise profitability and reduce costs for customers.
- **Flexibility:** CaaS providers can offer different service levels and pricing options to meet diverse customer needs.

In the CaaS model, illustrated in Figure 20, end-user customers pay for cooling services based on usage. A third party funds the capital, infrastructure, operation and maintenance costs, recovering these expenses through customer usage payments. This model benefits farmers by eliminating the economic barrier of upfront capital investment, allowing them to access the cold chain and become direct users without purchasing technology and infrastructure directly.

Figure 19: Illustrative CaaS model at farmgate level



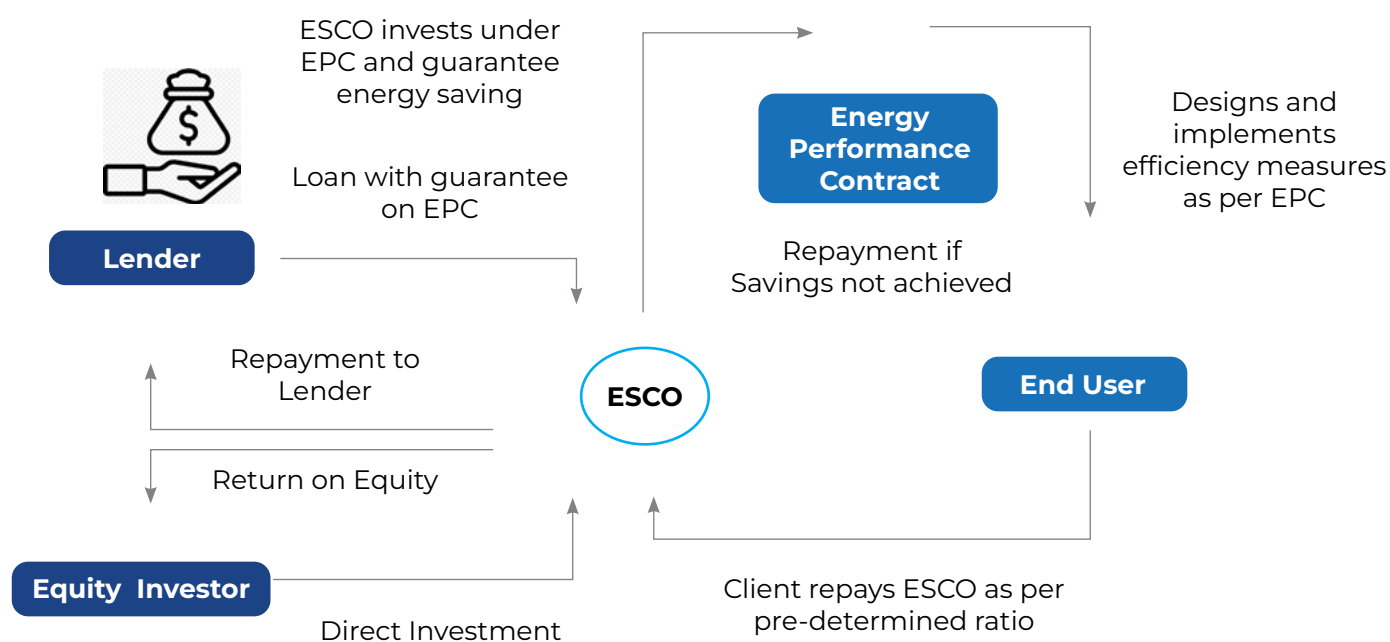
Energy performance contracts

Energy Performance Contracts (EPCs) offer a compelling solution for farmers to adopt energy-efficient cooling technologies without the barrier of upfront costs. This model allows farmers to upgrade their cold storage facilities through a revenue-sharing agreement with a service provider. Farmers benefit from reduced energy consumption and share the resulting cost savings with the provider. (Refer Figure 21 below)

EPCs offer several advantages:

- **Mitigated financial risk:** Eliminates the need for large upfront investments.
- **Access to expertise:** Provides access to cutting-edge technologies and expert knowledge for optimal system performance.
- **Increased profitability:** Enhanced energy efficiency leads to substantial cost savings and reduces post-harvest losses, improving overall farm profitability.
- **Sustainable practices:** Promotes environmentally friendly practices by reducing energy consumption.

Figure 20: EPC contracting through ESCO



Dealer financing

Dealer financing model aims to ease the financial burden on consumers. The model features two key components, which are:

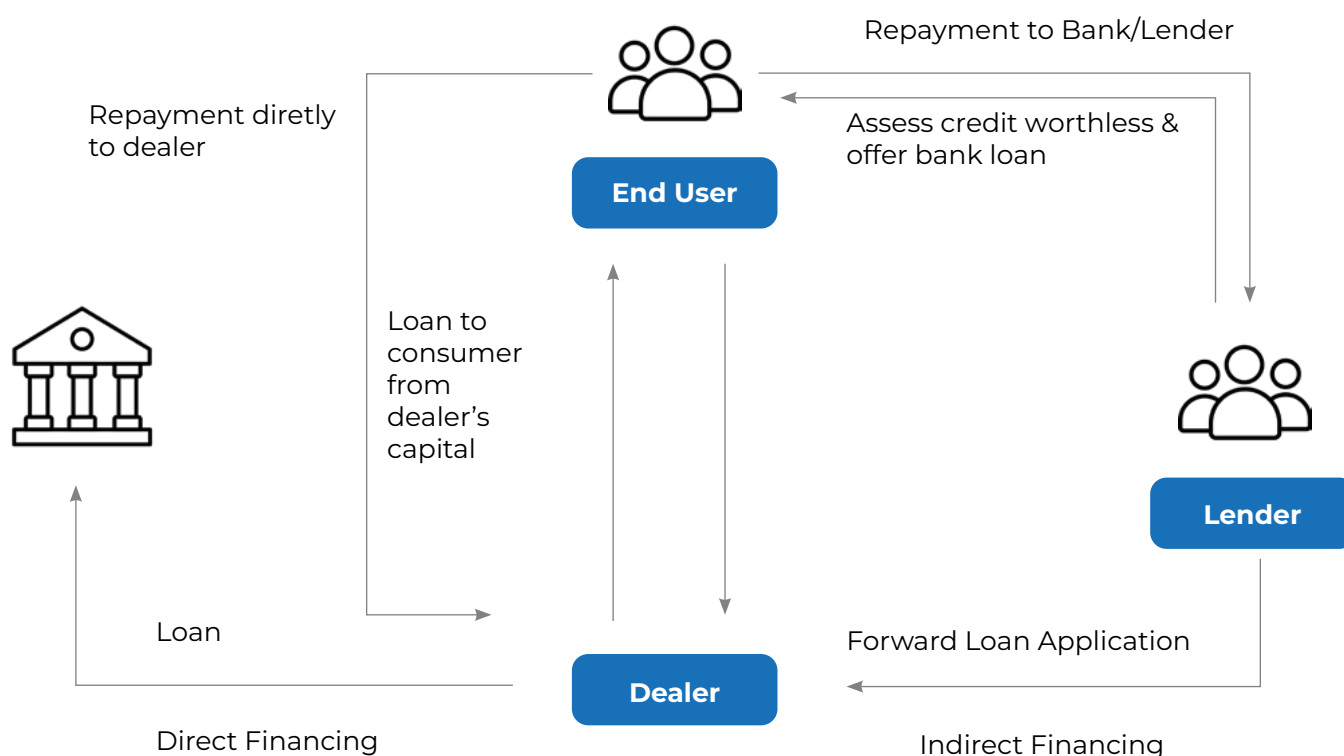
- **Direct supplier financing:** Technology suppliers provide loans directly to consumers, either through their own capital or partnerships with financial institutions. This significantly reduces upfront costs, removing a major barrier to entry for businesses seeking to upgrade their cooling systems.
- **Facilitated dealer financing:** Retailers play an active role in simplifying the financing process for consumers. They assist with loan applications, coordinate credit checks

with third-party lenders and provide a smoother, more approachable experience for securing financing. This streamlined approach encourages faster adoption by reducing complexity and time investment for consumers.

Benefits of dealer financing model

- Farmers benefit from reduced financial barriers to acquiring advanced cooling equipment, leading to better preservation and quality of produce. This can decrease post-harvest losses and lower operational costs through energy savings and enhance profitability. (Refer to Figure 22 below)

Figure 21: Illustration of dealer financing model



Franchise model

The cold storage franchise model presents a compelling opportunity to capitalise on the increasing demand for refrigerated storage solutions. By leveraging a network of franchisees, this model expands the reach of essential cold storage services while offering entrepreneurs a structured business framework. A franchisor with an established brand and proven operating system partners with individual franchisees. Together, they establish and operate cold storage facilities. This mutually beneficial relationship offers several key advantages:

For Franchisees:

- **Turnkey business model:** Benefit from a standardised and proven system for cold storage operations, including protocols for temperature control, inventory management and safety standards. This eliminates the guesswork of starting a business from scratch.
- **Brand recognition:** Leverage the franchisor's established brand and reputation to attract customers from day one. This pre-built brand equity translates to instant credibility and trust in the market.
- **Comprehensive support:** Receive ongoing support and training from the franchisor, covering everything from technical aspects of cold storage to customer service and marketing strategies. This ensures you have the tools and knowledge to succeed.
- **Infrastructure assistance:** Depending on the franchise agreement, receive assistance with essential infrastructure, including refrigeration equipment and initial setup

support. This reduces the initial investment burden and streamlines the launch process.

- **Strong market demand:** Tap into the growing demand for cold storage services, particularly for perishable goods like fruits, vegetables, dairy products and temperature-sensitive pharmaceuticals. This translates to a potentially lucrative and stable business opportunity.

For Franchisors:

- **Rapid expansion:** Expand the brand's footprint and market reach quickly and efficiently by partnering with driven entrepreneurs.
- **Reduced capital investment:** Leverage the capital and resources of franchisees to fuel expansion, minimising the financial burden on the franchisor.
- **Local market expertise:** Benefit from the local market knowledge and connections of individual franchisees, ensuring each location is strategically positioned for success.

Operational Management: Franchisees are responsible for the day-to-day operations of their cold storage facilities. This includes:

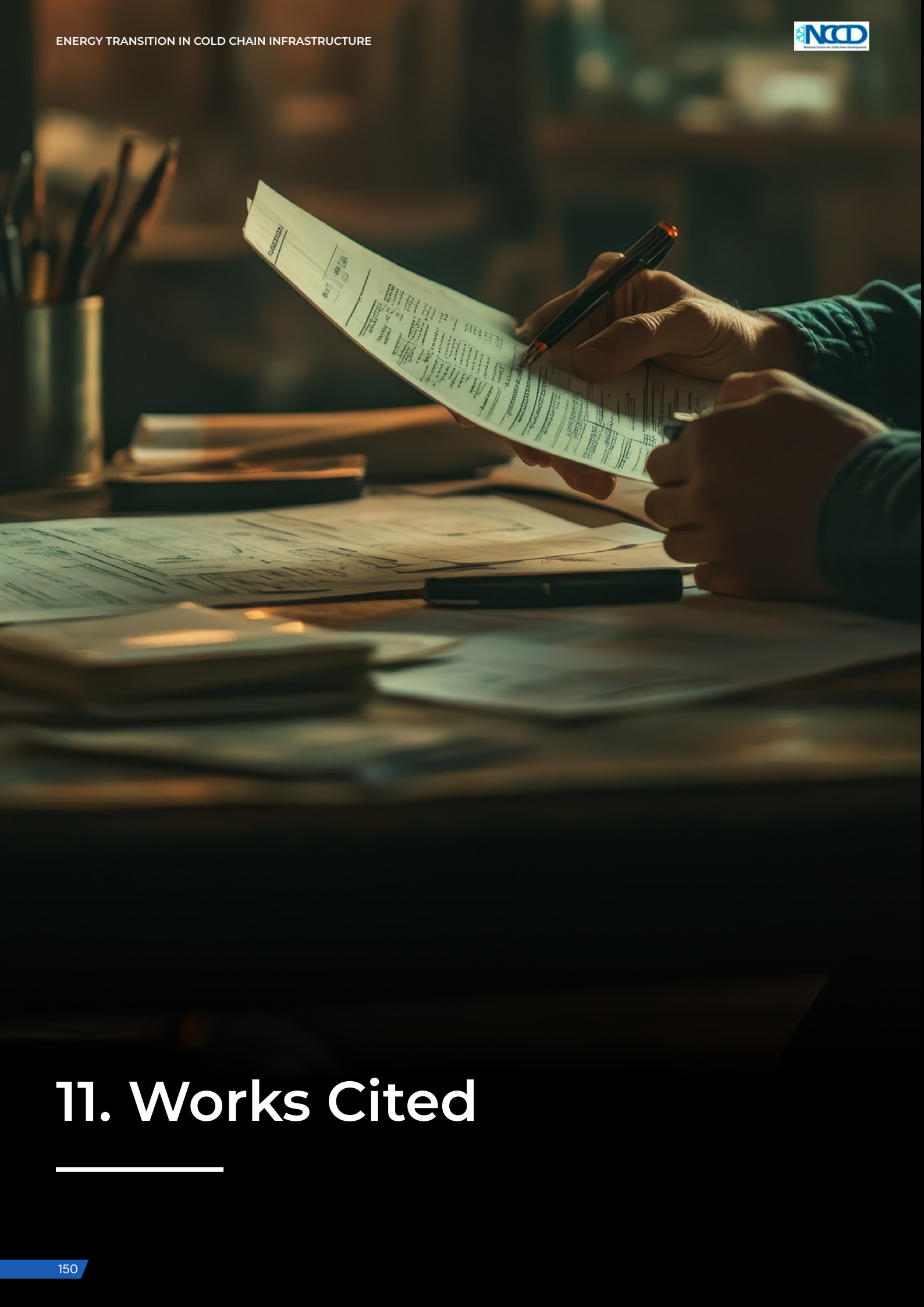
- **Staffing and management:** Hiring, training and managing a team to ensure efficient facility operations.
- **Customer service:** Providing excellent customer service and building strong relationships with clients.
- **Facility maintenance:** Ensuring the facility and equipment are well-maintained and compliant with industry standards.



10.5. Cold storage stock

No	States and UT	01.05.2024		31.08.2020	
		CS number	Capacity	CS number	Capacity
1	Andaman & Nicobar Islands (UT)	4	2,210	3	810
2	Andhra and Telangana	471	19,11,442	405	15,67,664
3	Arunachal Pradesh	2	6,000	2	6,000
4	Assam	45	2,16,388	39	1,78,096
5	Bihar	315	14,83,700	311	14,79,122
6	Chandigarh (UT)	7	12,462	7	12,462
7	Chhattisgarh	126	5,71,693	99	4,87,292
8	Delhi	97	1,29,857	97	1,29,857
9	Goa	29	7,705	29	7,705
10	Gujarat	1,023	40,42,770	969	38,22,112
11	Haryana	380	8,70,703	359	8,19,809
12	Himachal Pradesh	89	1,81,318	76	1,46,769
13	Jammu & Kashmir	85	3,22,515	69	2,50,169
14	Jharkhand	60	2,48,629	58	2,36,680
15	Karnataka	261	8,53,656	223	6,76,832
16	Kerala	202	96,655	199	81,705
17	Lakshadweep (UT)	1	15	1	15
18	Madhya Pradesh	315	13,64,003	302	12,93,574
19	Maharashtra	655	11,72,005	619	10,09,693
20	Manipur	2	4,500	2	4,500
21	Meghalaya	4	8,200	4	8,200
22	Mizoram	3	4,071	3	4,001
23	Nagaland	5	8,150	3	7,150
24	Orissa	182	5,79,321	179	5,72,966
25	Pondicherry (UT)	4	185	3	85
26	Punjab	770	26,06,203	697	23,15,096
27	Rajasthan	191	6,52,879	180	6,11,831
28	Sikkim	2	2,100	2	2,100
29	Tamil Nadu	188	3,99,690	183	3,82,683
30	Telangana	108	5,41,397	74	4,10,905
31	Tripura	14	46,354	14	46,354
32	Uttar Pradesh	2,481	1,50,89,883	2,406	1,47,14,235
33	Uttarakhand	60	2,06,621	55	1,91,314
34	West Bengal	517	59,52,997	514	59,47,311
	Total	8,698	3,95,96,277	8,186	3,74,25,097

2017		2014		2009	
CS number	Capacity	CS number	Capacity	CS number	Capacity
3	810	2	2,210	2	210
442	17,82,561	404	15,77,828	290	9,00,606
2	6,000	2	5,000	1	5,000
36	1,57,906	34	1,19,652	24	88,068
306	14,15,595	303	14,06,395	246	11,47,041
7	12,462	6	12,216	6	12,216
98	4,84,087	89	4,27,766	69	3,41,885
97	1,29,857	97	1,29,857	95	1,26,158
29	7,705	29	7,705	29	7,705
764	29,01,807	560	20,30,873	398	12,67,304
338	7,49,830	295	5,88,649	244	3,93,121
66	1,31,017	32	38,557	18	19,858
38	1,12,516	28	64,769	19	42,869
58	2,36,680	55	2,17,280	45	1,70,148
198	5,60,178	189	5,26,752	170	4,07,165
198	80,405	197	78,355	193	58,105
1	15	1	15	1	15
300	12,63,665	260	10,97,168	197	8,08,052
604	9,78,392	540	7,06,302	466	5,46,748
2	5,500	1	2,175	-	-
4	8,200	4	8,200	3	3,200
3	4,001	3	3,931	-	-
4	7,350	2	6,150	2	6,150
171	5,40,141	111	3,26,639	101	2,91,039
3	85	3	85	3	85
660	21,55,704	606	20,04,778	422	13,45,193
166	5,55,278	154	4,80,032	110	3,24,226
2	2,100	2	2,000	1	2,000
174	3,37,625	163	2,95,671	148	2,38,536
-	-	-	-	-	-
14	45,477	13	39,181	11	29,450
2,299	1,41,76,062	2,176	1,36,33,039	1,589	1,01,18,000
46	1,60,419	28	84,545	15	68,499
512	59,47,561	502	59,01,925	463	56,82,000
7,645	3,49,56,991	6,981	3,18,25,700	5,381	2,44,50,652



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