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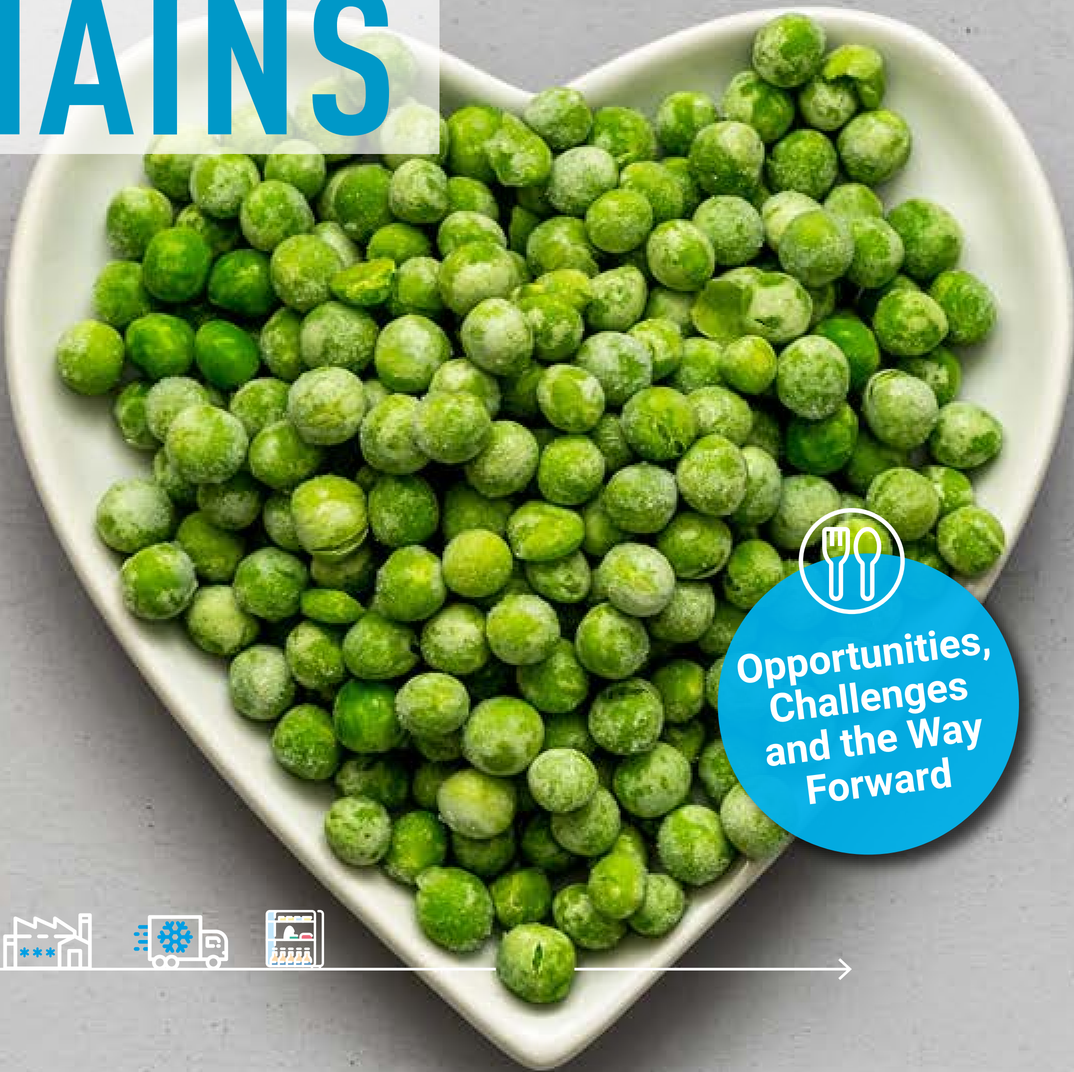
SUSTAINABLE FOOD COLD CHAINS



Opportunities, Challenges and the Way Forward

Cool Coalition

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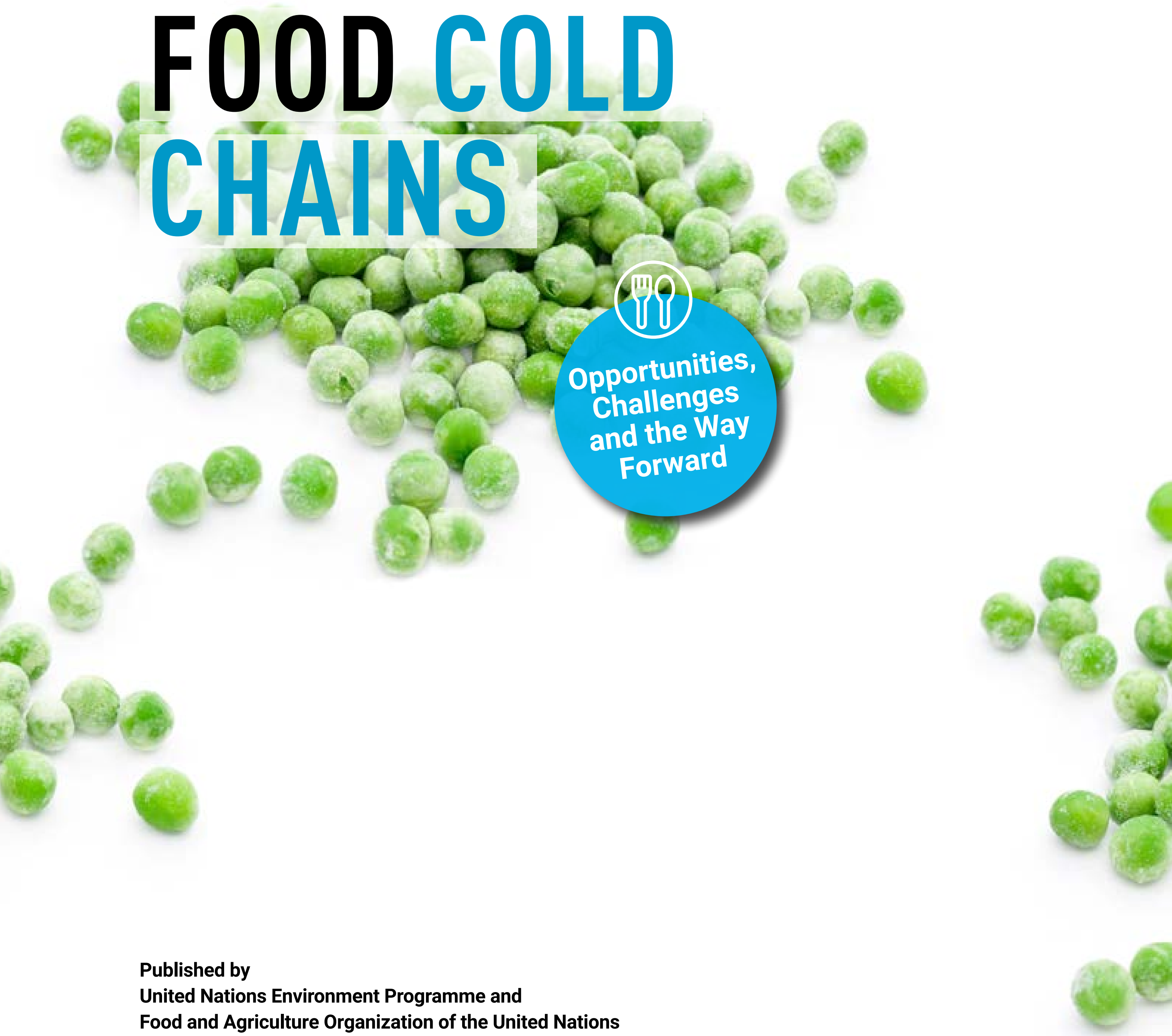

Opportunities, Challenges and the Way Forward

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FOREWORD I

The world is grappling with many interconnected crises. The triple planetary crisis of climate change, nature and biodiversity loss, and pollution and waste is accelerating. The war in Ukraine, and other protracted conflicts, are raising the prices of basic grains and threatening food security in many countries. These crises are undermining efforts to achieve the Sustainable Development Goals. Approximately 828 million people go hungry each year, and 3 billion cannot afford a healthy diet.

The shocking amount of food lost and wasted contributes to these crises. Of the total food produced for human consumption, an estimated 14 per cent is lost before the food reaches the consumer. The lack of effective refrigeration is a major contributor to this problem. However, as this report shows, sustainable food cold chains could avoid much of this loss and go a long way towards alleviating the crises.

Food loss post-harvest reduces the income of 470 million smallholder farmers by as much as 15 per cent – with developing countries hit the hardest. The food cold chain is responsible for 4 per cent of global greenhouse gas emissions, including from cold chain technologies and food loss and waste due to lack of refrigeration.

To feed the projected global population of 9.7 billion in 2050, food production will have to increase – meaning the need for more food cold chains. As food cold chains require energy, a business-as-usual approach to development will exacerbate the climate crisis challenges.

This report explores how food cold chain development can become more sustainable and makes a series of important recommendations. These include governments and other cold chain stakeholders collaborating to adopt a systems approach and develop National Cooling Action Plans, backing such plans with financing and targets, and implementing and enforcing ambitious minimum efficiency standards.

The Montreal Protocol on Substances that Deplete the Ozone Layer – a universally ratified multilateral environmental agreement – can contribute to mobilizing and scaling up solutions for delivering sustainable, efficient and environmentally friendly cooling through its Kigali Amendment and Rome Declaration. Reducing non-CO_2 emissions, including refrigerants used in cold chain technologies is key to achieve the Paris Agreement targets, as highlighted in the latest mitigation report from the Intergovernmental Panel on Climate Change (IPCC).

At a time when the international community must act to meet the Sustainable Development Goals, sustainable food cold chains can make an important difference. We strongly encourage all stakeholders to implement the findings of this report, to transform agrifood systems to be more efficient, more inclusive, more resilient and more sustainable; to improve food security; cut greenhouse gas emissions; create jobs; and help end hunger and poverty – for better production, better nutrition, a better environment and a better life for all, leaving no one behind.

Inger Andersen
Executive Director, UNEP

QU Dongyu
Director-General, FAO

FOREWORD II

Ensuring an efficient deployment of sustainable food cold chains worldwide represents a key building block for enhancing a low-emission and climate-resilient development pathways. At the same time, it provides an effective contribution to the Sustainable Development Goals (SDGs).

In fact, unavailable or under-developed food cold chains affect the capacity to maintain the quality and safety of food and contribute to food losses and waste, whose impacts are detrimental not only for people's livelihoods, but also for the environment. Nowadays, one-third of food production has been calculated to be still lost or wasted, and the world cannot afford a similar situation in the context of a global population that is projected to reach 9.7 billion by 2050 and of a steadily growing urbanization. Additionally, food loss and waste contributes to around 8% of total greenhouse gas emissions, as highlighted by the FAO. The International Institute of Refrigeration reports that emissions from food loss and waste due to lack of refrigeration, totalled an estimated 1 gigaton of CO_2 in 2017.

The COVID-19 crisis has made this clear more than ever, not only because the availability of capillary cold chains is essential for global vaccine distribution, but also as adaptive societal behaviours during the pandemic gave evidence about the importance of having a flexible and resilient food cold chain infrastructure to ensure supply for rapidly changing consumers' demand.

The Italian Government, together with many other national and international partners, strongly believes that addressing these challenges urgently and holistically has therefore become of paramount importance in the context of climate action and the pursuit of the Sustainable Development Goals outlined in the Agenda 2030. However, in order to be effective, the promotion of sustainable cold chains to tackle food waste needs to be addressed throughout a series of complex, inter-linked technological, business, industrial and policy-related dimensions, which requires thinking systemically and adopting integrated approaches domestically and internationally. Furthermore, efforts need to be carried out globally to ensure that a skilled workforce can support the transition to the development of advanced, climate-friendly technologies, thus enabling the development of food cold chains to a key driver of increasing green jobs.

Domestically, Italy has taken up the challenge, for example by designing specific legislative frameworks to promote food waste reduction as well as by fully implementing the EU F-Gas Regulation. The Italian industry also has a tradition of expertise in the field of high-level climate-friendly technology for cold chain and refrigeration systems.

However, the role of international cooperation in this field is fundamental. In particular adoption of the Kigali Amendment provides a trigger to enhance global action on climate-friendly cold chains, as demonstrated at the 31st Meeting of the Parties of the Montreal Protocol on November 2019 where more than 80 Parties have joined voluntarily the Rome Declaration on "the contribution of the Montreal Protocol to sustainable cold chain development for food waste reduction". The Declaration, launched as a joint initiative by Italy, the UNEP Ozone Secretariat and the FAO, aims to strengthen cooperation at all levels between relevant stakeholders to exchange knowledge and promote innovation of energy-efficient solutions and technologies.

I therefore wish to commend the authors and the publishing of this report, which represents a milestone in this context as it brings in the most advanced knowledge, solutions, best practices and recommendations currently available globally to set action for defining and promoting the sustainability of food cold chains and for identifying sustainable solutions worldwide, which can contribute in delivering the SDGs and ambitious climate targets.

Alessandro Modiano

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ABBREVIATIONS

˚C Degrees Celsius

ACES Africa Centre of Excellence for Sustainable Cooling and Cold Chain

CaaS Cooling as a Service

CO_2 Carbon Dioxide

FAO Food and Agriculture Organization of the United Nations

GCCA Global Cold Chain Alliance

GFCCC Global Food Cold Chain Council

GWP Global Warming Potential

HCFC Hydrochlorofluorocarbon

HFC Hydrofluorocarbon

HFO Hydrofluoro-olefin

kW Kilowatt

MEPS Minimum Energy Performance Standards

MW Megawatt

NCAP National Cooling Action Plan

NCCD National Centre for Cold-chain Development

ODP Ozone Depletion Potential

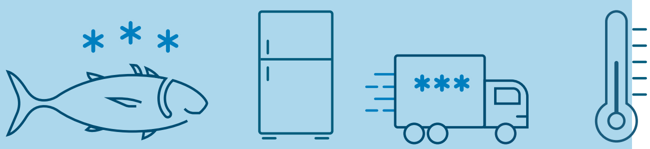
OECD Organisation for Economic Co-operation and Development

SDG Sustainable Development Goal

UN United Nations

UNEP United Nations Environment Programme

UNIDO United Nations Industrial Development Organization



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SUMMARY

Of the total food produced for human consumption, an estimated 14 per cent is lost (Food and Agriculture Organization of the United Nations [FAO] 2019), and an estimated 17 per cent is wasted (UNEP 2021), costing the global economy an estimated $936 billion a year (FAO 2014a). **The lack of effective refrigeration is a leading contributor to this challenge, directly resulting in the loss of 526 million tons of food production, or 12 per cent of the global total, in 2017** (International Institute of Refrigeration [IIF/IIR] 2021a). This is enough to feed an estimated 1 billion people in a world where currently 811 million people are hungry and 3 billion are unable to afford a healthy diet (FAO 2022).

The unavailability of robust food cold chains to maintain the quality, nutritional value and safety of food products has ramifications for people's health. A food cold chain is an integrated temperature-controlled food distribution system that ensures that perishable produce and/or temperature-sensitive products are kept at their optimum temperature and environment, from source to destination. It is a complex system that has many static and moving elements and that requires accountability from multiple levels, including farmers, aggregators, processors and manufacturers, distributors, retailers and consumers.

Populations in most developing countries depend heavily on agriculture for their livelihoods, **making the development of food cold chains a powerful tool to boost incomes and foster economic growth.** Food loss during the post-harvest period reduces the income of 470 million smallholder farmers by as much as 15 per cent (Rockefeller Foundation 2013).

STATUS AND IMPLICATIONS OF CURRENT FOOD COLD CHAINS

The global food cold chain capacity has been growing in recent decades. However, this growth is uneven. Many developing countries need substantial additional capacity at all stages to ensure uninterrupted connectivity from farm to fork, as well as the skills required to install and maintain cooling equipment. Even in developing countries where cold chain infrastructure is growing, the expansion of throughput may be limited due to less-than-optimal utilization of the existing capacity. Challenges include a lack of relevant engineering capacity (resulting in poor equipment maintenance and downtime), misapplied business models and mismanaged forward or backward linkages, among others. The result is inefficiencies in energy and resource use, lower returns on investment, and unwarranted financial overruns. Rapid development in sustainable food cold chain infrastructure and technology requires parallel updating of skillsets and best practices, to minimize operational challenges as well as food and financial losses.

The food cold chain also has implications for global climate change and the environment. Emissions from food loss and waste due to lack of refrigeration totalled an estimated 1 gigaton of carbon dioxide (CO_2) equivalent in 2017 (IIF/IIR 2021). **Overall, the food cold chain is responsible for around 4 per cent of total global greenhouse gas emissions, including emissions from cold chain technologies and from food loss and waste due to lack of refrigeration** (IIF/IIR 2021). Emissions from the cold chain itself are set to rise significantly as new cooling-related infrastructure comes online in developing countries.

THE BENEFITS OF SUSTAINABLE FOOD COLD CHAINS

Sustainable food cold chains are key for improving human well-being, boosting economic growth and delivering socio-economic development through the United Nations Sustainable Development Goals (SDGs) while simultaneously achieving the objectives and targets of the Paris Agreement and the Montreal Protocol. The contribution of food cold chains to the SDGs spans multiple areas. Key among these are amplifying farm-level productivity through market connectivity, reducing food losses in the post-harvest stages, hence safeguarding the quantity and quality of food produced to ensure food and nutritional security, and countering the future effects of climate change on the global food supply system. **However, these benefits are whittled away, and the value of the food cold chain diminished, if its management and operations add to greenhouse gas emissions and pollute the environment.** Sustainable food cold chains must address all the functional areas from the perspective of maximizing the economic, social and environmental benefits from the cold chain while minimizing the impact of practices that negate the gains. Therefore, sustainable food cold chains infer system-wide awareness of the impact of wide-ranging activities undertaken to amend and improve the weak spots that subtract from other gains.

DESIGNING SUSTAINABLE FOOD COLD CHAINS

Developing a sustainable food cold chain presents a wicked problem with diverse drivers and barriers, all interconnected and with multiple feedback loops, varying by country and depending on local economic, environmental, social, cultural and political circumstances. It is about more than procuring and installing solar-powered cold rooms at the farm gate or chiller cabinets with lower global warming potential refrigerants in supermarkets. At a systems level, cold chain sustainability is also impacted by, among others, post-harvest inventory management, packaging and handling materials, waste management, heat reclaim, and the operational models and procedures employed. Key challenges revolve around access to reliable and affordable energy, behavioural issues, skillsets, and the business and financing models that underpin the overall investment.

Solutions are needed to reduce the greenhouse gas emissions from the global food cold chain and to make it more environmentally sustainable. However, the decision criteria of food cold chain developers and investors today tend to be narrowly focused on simply measuring the savings from energy efficiency and the emissions impact from refrigeration. A wider systems approach is needed that adds focus on other core functions and cross-sectoral activities in the food cold chain that contribute to the sustainability and resilience of the agri-food system.

There is increasing recognition that an end-to-end system-level approach is necessary to deliver sustainable food cold chains and to tackle the barriers to success in the most effective and efficient manner. However, this can be hard to successfully execute in the real world, as it requires cooperation from multiple stakeholders and contains many interdependencies. Hence, current applications of such an approach are limited, and the majority of case studies involved in this report are good practices that aim to address individual issues within the food cold chain system and can often deliver quick incremental wins. These case studies are included to inspire stakeholders during the short- and medium-term development stages of the food cold chain.

OBJECTIVES OF THE REPORT

This report highlights the complexity of food cold chain development globally and explores how it can evolve to become more sustainable. The main objectives of the analysis are to provide an overview of the status, drivers and implications of food cold chains globally; to describe the benefits of sustainable food cold chains; to identify the key drivers, barriers and opportunities in moving towards them; and to showcase existing technologies, projects, finance and business models, and policies, both locally and internationally. The report concludes with recommendations for a comprehensive systems approach to accelerate action and to foster cooperation among the diverse actors to advance more sustainable food cold chains globally.

Over the long term, achieving a sustainable food cold chain will require a shift in how we approach cold chain development away from linear to circular by understanding interconnected and dynamic relationships, and feedback loops within the whole system, as highlighted in the recommendations.

KEY RECOMMENDATIONS FOR DEVELOPING A SUSTAINABLE COLD CHAIN

- Governments, working with industry and other stakeholders, **should quantify and benchmark the energy use and greenhouse gas emissions** in the existing food cold chain, identify data gaps, develop forecasts and identify opportunities for reductions.
- Governments and other cold chain stakeholders **should take a holistic systems approach to food cold chain provision**, recognizing that cooling technologies alone are not sufficient to make an efficient cold chain.
- Governments and other cold chain stakeholders **should collaborate and undertake cold chain needs assessment** and develop costed and sequenced National Cooling Action Plans to provide the underlying direction for holistic and sustainable cold chain infrastructure creation and to rationalize cold chain programmes across ministries.
- Governments **should implement and enforce ambitious minimum efficiency standards** as well as robust monitoring and enforcement to prevent illegal imports of inefficient cold chain equipment and refrigerants.
- In line with National Cooling Action Plans, governments **should develop costed and sequenced five-year plans, missions, policies and dedicated agencies/departments**, and provide financial assistance and capacity support for sustainable food cold chain components, with the aim of achieving seamless movement of agricultural products from farm to fork.
- Governments, working with industry and relevant stakeholders, **should build necessary skills and capacity as well as finance and business models in developing countries** to support cold chain industry engagement and technology deployment at scale.
- Governments, working with industry and relevant stakeholders, **should build digital twins to guide "build-to-suit" projects** for local implementation of integrated food cold chain.
- Industry and civil society stakeholders, backed by governments, **should run large-scale system demonstrators to show impact** and how interventions can work together to create sustainable and resilient solutions for scaling.
- Governments and other cold chain stakeholders **should collaborate with relevant institutions** to quantify and value the broader socio-economic impacts of sustainable food cold chains, taking into account poor, disadvantaged and marginalized food producers and their communities, as well as women and youth.
- To encourage a collaborative ecosystem of stakeholders, to coordinate on above recommendations and with developments worldwide, **governments should institute a multi-disciplinary centre for cold chain development**. Such national-level centres can also serve to liaise with other international organizations on matters related to the development of sustainable cold chains.

01 INTRODUCTION

Food production will need to increase significantly to feed the expected human population of 9.7 billion by 2050 (United Nations [UN] 2019). This would require closing the 56 per cent[1] gap in the global food supply between what was produced in 2010 and what will be needed in 2050 (World Resources Institute [WRI] 2019). **Feeding the global population also means ensuring that the food that is produced does not go to waste. The lack of effective cold chain to maintain the quality, nutritional value and safety of food is a leading contributor to global food loss and waste,** which has ramifications for people's health and livelihoods.

A food cold chain is an integrated temperature-controlled food distribution system that helps to ensure the quality, nutritional value and safety of perishable produce and/or temperature-sensitive products. The cold chain plays a key role in reducing food loss and waste post-harvest and in extending the shelf life of products such as fruits, vegetables, dairy, meat and fish. It is a complex system that requires accountability at multiple levels and that includes activities related to packaging, precooling, aggregation, transport and storage.

Global food cold chain infrastructure has been growing rapidly in recent decades. However, this growth is uneven. While most developed countries have well-established food cold chains, many developing countries, whose populations continue to depend heavily on agriculture for their livelihoods, do not. **Developing and emerging economies need substantial additional capacity at all stages of the cold chain to ensure uninterrupted connectivity from farm to fork.**

1 Measured in total calories. As an alternative to measuring the gap in total calories, the FAO uses a price-weighted index and estimates that food production in 2050 should increase by 60 per cent relative to 2005/07 levels to meet the demand (Alexandratos and Bruinsma 2012). This figure is often misquoted as 70 per cent (UN 2019), which is the previous FAO estimate (FAO 2014) (WRI 2019; Alexandratos *et al.* 2006; FAO 2021a).

Even in developing countries where cold chain infrastructure is growing, the expansion of throughput may be limited due to less-than-optimal utilization of the existing capacity. Challenges include a lack of access to reliable and affordable energy, relevant engineering capacity (resulting in poor equipment maintenance and downtime), misapplied business models and mismanaged forward or backward linkages, among others. The result is inefficiencies in energy and resource use, lower returns on investment and unwarranted financial overruns and food safety risks when there is a cold chain break for frozen products. Rapid development in food cold chain infrastructure and technology requires parallel updating of skillsets and best practices, to minimize operational challenges and financial losses, including food loss.

The food cold chain also has implications for global climate change and the environment. Emissions from food loss and waste due to lack of refrigeration totalled an estimated 1 gigaton of carbon dioxide (CO_2) equivalent in 2017 (IIF/IIR 2021). **Overall, the food cold chain is responsible for around 4 per cent of total global greenhouse gas emissions,** including emissions from cold chain technologies (i.e., electricity, fuel and refrigerant emissions) and from food loss and waste due to lack of refrigeration (IIF/IIR 2021). Emissions from the food cold chain itself are set to rise significantly as new cooling-related infrastructure comes online in developing countries.

Solutions are needed both to reduce emissions from the global food cold chain and to make this infrastructure more environmentally sustainable. However, developing a sustainable food cold chain is about far more than just procuring and installing solar-powered cold rooms at the farm gate or chiller cabinets with lower global warming potential refrigerants in supermarkets. It presents a wicked problem with diverse drivers and barriers, all interconnected and with multiple feedback loops, varying by country and depending on local economic, environmental, social, cultural and political circumstances.

At a systems level, food cold chain sustainability is impacted by, among others, post-harvest inventory management, packaging and handling materials, heat reclaim and waste management and the operational models and procedures being used. Key challenges revolve around behavioural issues, operational and commercial skillsets, and the business and financing models that underpin the overall investment. **Over the long term, achieving a sustainable food cold chain will require shifting the approach to cold chain development from linear to circular, recognizing the interconnected and dynamic relationships and feedback loops within the whole system.**

This report highlights the complexity of food cold chain development globally and explores how it can evolve to become more sustainable. The report is structured as follows:

02 **Chapter 2** provides an overview of the food loss challenge and summarizes the status, drivers and implications of food cold chains globally.

03 **Chapter 3** describes sustainable food cold chains and their diverse benefits.

04 **Chapter 4** identifies the key drivers and barriers in moving towards sustainable food cold chains. It showcases existing technologies, projects, finance and business models, and policies, both locally and internationally, and highlights the need for end-to-end, system-level approaches to achieve a sustainable food cold chain.

05 **Chapter 5** provides recommendations for a comprehensive systems approach to accelerate action and to foster cooperation among the diverse actors to advance more sustainable food cold chains globally.

The Annex provides a list of case studies showing good practices that aim to address specific issues within the food cold chain system and that can often deliver quick incremental wins. These cases are included to inspire stakeholders during the short- and medium-term development stages of the food cold chain.

FOOD COLD CHAINS: A GLOBAL PERSPECTIVE

02

2.1 FOOD VALUE CHAIN AND THE KEY ROLE OF THE COLD CHAIN

A food value chain is a set of interlinked steps involved in the production, storing, processing, marketing, distribution and consumption of food. Food producers are at one end of the value chain, while consumers are at the other end. Between the point of food production and the point of consumption, various processes and actors in the value chain add value to the food product, in several ways. This includes primary processes (such as sorting and grading), packaging, precooling, storing, food processing and transport, all of which allows the product to reach the consumer in a manner that upholds a food's quality and safety, minimizing both food and economic losses. Figure 1 outlines the main steps through which food passes before reaching the consumption stage.

Figure 1. A generic food value chain

Source: FAO 2021, Puri, M., Rincon, L., & Maltsoglou, I. (2021). Renewable energy for agrifood chains: Investing in solar energy in Rwanda. FAO 2016, Puri, Manas. How access to energy can influence food losses. A brief overview.

While food value chains exist in all countries in some form, the level to which they are developed varies widely. In developed countries, the availability of modern equipment, reliable and affordable energy, human capacity and easy access to other inputs ensures that agriculture value chains are often mechanized, more efficient and sophisticated compared to developing countries. In developing countries, value chains tend to be rudimentary, rely on traditional sources of energy, often lack modern processing, storage and transport capacity, suffer from lack of human resources and have poor market linkages.

The extent to which the food value chain is developed also impacts the variety of food that can be produced and is available in the market. For example, in developed countries where food value chains are well developed, a large share of milk is processed into higher-value products such as cheese and milk powder, whereas in many countries in sub-Saharan Africa, for example, where the extent of milk value chains is limited, relatively small amounts of milk are processed into higher-value products. Food processing can take many forms – including freezing, curing, drying, pasteurizing, fermenting and canning – and it can provide significant economic benefits by extending the usable life of products. This allows for reductions in food loss, the use of produce to generate value-added products and the sale of products in the off-season (Box 1).

Box 1. Coffee freeze-drying to preserve flavour and aroma

Buencafé is a Colombian company that produces premium soluble coffee and is part of the Colombian Coffee Growers Federation (FNC). Industrial-scale production uses freeze-drying technology. The process starts with the collection of fresh green coffee, which once roasted is ground and immersed in pure spring water to extract the soluble coffee compounds. The extract is frozen at around -5 degrees Celsius (˚C) to preserve the flavour and aroma, then the ice is removed through cryo-concentration. Finally, the coffee extracts are deep-frozen at -50°C using vacuum pressures (less than one-thousandth of atmospheric pressure), followed by the remaining ice sublimation. For the refrigeration system, since 1990, Freon gas (R-22) has been replaced with ammonia (R-717).

Buencafé has increased its energy efficiency, reducing the energy consumption per kilogram of freeze-dried coffee from 40 kilowatt-hours (kWh) in 2015 to 34 kWh in 2018. Thanks to more efficient use of the natural resources available and the adoption of circular economy strategies, the company has been able to start substituting fossil fuels along the process. Buencafé uses coffee wastes and natural gas as energy sources for heat production, while supplying a large share of the electricity using a 5 megawatt (MW) solar photovoltaic system and a 2.5 MW hydropower system.

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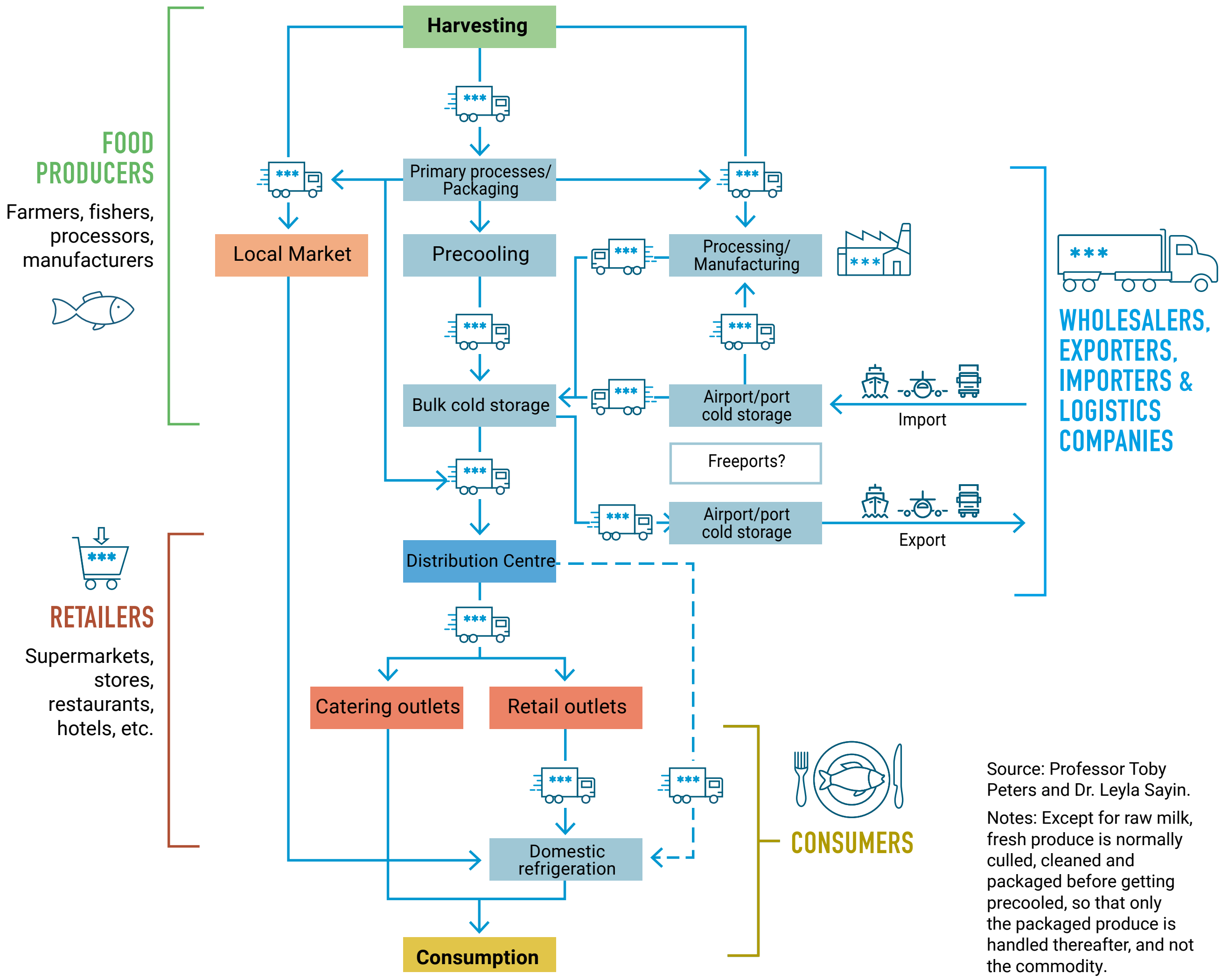
Source: FAO, 2022 and Colombian Coffee Growers Federation (FNC), 2019. Informe de Sostenibilidad 2015-2018 [In Spanish] (2019). https://federaciondecafeteros.org/app/uploads/2019/11/Informe-de-Sostenibilidad-2015-2018.pdf. Accessed 21 January 2022.

For perishables, such as meat, dairy, fruit and vegetables, having access to refrigeration and a cold chain is imperative to maintain food quality and safety, and to reduce losses along the supply chain. However, temperature control and cooling are energy-intensive processes and, if powered by fossil fuels, can result in significant greenhouse gas emissions. Furthermore, conventional refrigeration equipment in the food cold chain uses refrigerants with high global warming potential (GWP), which can further exacerbate total greenhouse gas emissions from the cold chain.

A cold chain is an integral part of the food value chain. It is an integrated temperature-controlled food distribution system that ensures that perishable produce and/or temperature-sensitive products are kept at their optimum temperature and environment (which can differ depending on specific food characteristics) to maintain their quality, nutritional value, and safety, from source to destination. It involves a broad range of activities, from farm to fork, as well as various stakeholders, from producers to consumers.

A food cold chain is a complex system that has many static and moving elements (Fig. 2). As such, it requires accountability from multiple levels, including farmers, aggregators, processors and manufacturers, distributors, retailers and consumers. It typically involves stages including primary processing (such as sorting and grading), packaging, precooling (Box 2), refrigerated warehouses, cold storage at the wholesale/retail level, catering, mobile components (such as refrigerated carriage on trucks, ships and aircraft, and cooled street vending carts) as well as domestic storage until consumption.

Figure 2. Typical food logistics cold chain steps and stakeholders



Source: Professor Toby Peters and Dr. Leyla Sayin.

Notes: Except for raw milk, fresh produce is normally culled, cleaned and packaged before getting precooled, so that only the packaged produce is handled thereafter, and not the commodity.

Box 2. What is the difference between precooling and cold storage?

Precooling or primary chilling is the controlled and rapid removal of heat from freshly harvested or slaughtered produce prior to storage or transport. It requires high-capacity refrigeration and optimized operation to minimize weight loss from products. Precooling is an essential first step in the fresh food cold chain. It is one of the most effective methods to maximize the shelf life of fresh produce (while maintaining nutritional quality) and to reduce the energy load in the remainder of the food cold chain (Sullivan, Davenport and Julian 1996).

However, precooling is often overlooked in the developing world with the focus on cold storage. The cold store is a refrigerated warehouse with suitably sized chamber capacities for the storage of precooled produce. The cooling capacity of cold stores is designed to maintain the temperature of incoming goods and not to extract heat as is the case with a chiller/precooler. Thus, it is important to consider precooling independently from cold storage, as it requires specially designed equipment (Elansari 2009).

There are a variety of precooling methods, such as chamber cooling, blast chilling, hydrocooling, ice cooling and vacuum cooling (Table 1). Selection of the precooling method depends on several factors, including the product characteristics as well as criteria such as the air temperature, relative humidity, temperature reduction requirements, refrigeration load, desired cooling rate and operating cost.

Table 1. Examples of precooling methods for fruits and vegetables

Method	Description	Suitable produce types
Chamber cooling	The slowest precooling method, in which produce is placed in a refrigerated room where it is exposed to cold air.	Produce that does not deteriorate rapidly; however, not suitable for produce that require rapid and immediate cooling after harvest (e.g., strawberries).
Blast chilling	High-velocity cold air is circulated through produce. Provides a higher cooling rate than chamber cooling. Systems range from the most basic in which cool air is circulated through the produce in an insulated chamber by using fans, to conveyorized tunnels or spirals.	Many types of fruits and vegetables.
Hydro-cooling	Cold water is applied to produce through submersion or sprinkling/spraying. Removes heat at a faster rate than forced-air cooling, since the water has a much higher heat transfer coefficient than air, and a given volume of water can remove more heat than the same volume of air at the same temperature.	Many types of fruits and vegetables, but not suitable for produce susceptible to wetting (e.g., berries).
Ice cooling	Instead of cold water, crushed or slurry ice is used to rapidly cool down the produce.	Effective for produce with high respiration (e.g., broccoli), but not suitable for produce that could be damaged by such low temperatures (e.g., tomatoes, squash, cucumbers, onions) and/or susceptible to wetting (e.g., berries).
Vacuum cooling	A vacuum system evacuates the air in the chamber, causing rapid evaporation of water on the surface of produce, cooling it down. Can allow for faster cooling down of produce than other methods.	Produce with a high surface-to-volume ratio, such as leafy vegetables. May cause weight loss in the produce due to the removal of moisture. To prevent excessive water loss, water can be applied during the process.

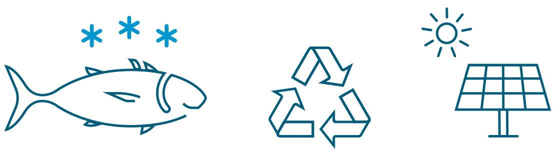
Source: Elansari 2009; FAO 2009; James and James 2014; Dumont, Orsat, and Raghavan 2016; Mercier *et al.* 2019

Box 2. What is the difference between precooling and cold storage? (continued)

Precooling is also an important step in the milk supply chain and can improve the quality of milk and reduce the storage refrigeration load, thereby reducing energy needs and costs. Precooling reduces the difference between the milk temperature after milking and to the required storage temperature of 4°C before entering the bulk tank to be cooled further. This is typically achieved by plate or pipe coolers using water from the mains supply, well or groundwater (Bennett *et al.* 2015). A plate cooler consists of a series of stainless-steel plates. Cold water flows along one side of each plate, and milk flows along the other in the opposite direction, and heat is transferred through the plates from milk to water. Pipe coolers work similarly. A pipe cooler consists of two stainless-steel tubes, with one tube inside the other, where milk flows in the inner tube and water flows in the outer tube.

The food cold chain plays a significant role in any perishable food supply chain, as time and temperature are critical variables in post-harvest management. For example, many horticultural products deteriorate at the same rate in one hour at a high temperature of 25°C as they do in one week at a low temperature of 1°C (Brosnan and Sun 2001). Degradation processes start immediately after harvest, slaughter or collection and continue through the supply chain until the produce is spoiled or consumed. Respiration, transpiration, enzymatic breakdown and microbial growth increase with temperature, leading to both quantitative losses (due to water loss and decay) and qualitative losses (due to losses in, for example, texture, flavour, nutritional quality and safety) (Kader 2002; Kitinoja 2013).

Other environmental parameters that affect the usable or saleable life of produce and products include their moisture content and the composition of the surrounding air. These parameters need to be managed throughout the food cold chain. In addition, the cold chain must consider the packaging used, the type of material handling equipment, and other processing and logistic systems. To ensure meaningful shelf life (presence on retail and kitchen shelves) for perishable food items, the cold chain can benefit greatly from the digitalization of its operations and monitoring activities.



2.2 FOOD LOSS AND ITS IMPLICATIONS

Of the total food produced for human consumption, an estimated 14 per cent is lost (FAO 2019) and an estimated 17 per cent is wasted (UNEP 2021), costing the global economy an estimated $936 billion a year[2] (FAO 2014a). The unavailability of cold chains during food processing, packaging, distribution and consumption is a key contributor to food loss. In 2017, less than half (45 per cent) of the food that required refrigeration worldwide was refrigerated (IIF/IIR 2021). The lack of effective refrigeration directly resulted in the loss of 526 million tons of food production, or 12 per cent of the global total (IIF/IIR 2021). This is enough to feed an estimated 1 billion people in a world where 811 million people are hungry and 3 billion are unable to afford a healthy diet (FAO 2022). Even in North America and Europe, 8 per cent of the population does not have regular access to safe, nutritious and sufficient food (FAO 2020).

Food loss is particularly high in the developing world. While developing countries are home to nearly 80 per cent of the world's harvested cropland, they refrigerate only around 20 per cent of the perishable food they produce (compared with 60 per cent in developed countries) (IIF/IIR 2020a). In India, post-harvest losses for some crops exceed 40 per cent, and only around 4 per cent of the country's food moves through the cold chain, compared with 70 per cent in the United Kingdom (University of Birmingham 2017). In Rwanda, only 5 per cent of firms in the food and agriculture sector have refrigerated trucks, and only 9 per cent have a cold room to store fresh produce (National Industrial Research and Development Agency 2019; World Bank 2020a). In the case of small and marginal farmers, where the majority of post-harvest food losses occur, functional cold chains are almost completely absent (less than 1 per cent of country's cold chain capacity) (National Agricultural Export Development Board 2019; World Bank 2020b).

The unavailability of robust cold chains to maintain food stability has ramifications for people's livelihoods and health, contributing to food safety and nutritional challenges. Food loss during the post-harvest period reduces the income of 470 million smallholder farmers by as much as 15 per cent (Rockefeller Foundation 2013). Meanwhile, poor diet causes one in five deaths globally, and around 600 million people (nearly 1 in 10) fall ill due to foodborne diseases, with around 420,000 of them dying annually, due in part to the lack of a functional cold chain (Afshin *et al.* 2019; World Health Organization 2021).

Food loss also has wider costs to the climate and the environment. Global food loss and waste resulted in greenhouse gas emissions totalling an estimated 4.4 gigatons of CO_2 equivalent (based on the FAO's 2011 assessment of food loss and waste volumes), or around 8 per cent of the global total (FAO 2014). If food loss and waste were a country, it would be the third largest emitter of greenhouse gases after China and the United States (FAO 2014). These emissions come from a variety of sources, such as food production, wasted electricity and heat during processing and manufacturing, energy used to store and transport food, land-use change and deforestation, and emissions from landfills. Emissions from food loss and waste due to lack of refrigeration specifically totalled an estimated 1 gigaton of CO_2 equivalent in 2017[3] (IIF/IIR 2021). As climate change-related extreme weather events such as droughts and flooding potentially lead to reductions in food production capabilities, food losses may become even less acceptable.

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2 Boston Consulting Group estimated in 2018 that annual food loss and waste may reach 2.1 billion tons, worth $1.5 trillion, by 2030 (Hegnsholt *et al.* 2018).

3 This is in line with the 2015 estimate from the Global Food Cold Chain Council (GFCCC) based on the FAO's 2011 assessment of food loss and waste volumes. According to the GFCCC, food loss and waste due to the lack or inefficiencies of cold chains generated 1 gigaton of CO_2 equivalent in 2011 (GFCCC 2015).

Establishing robust food cold chains could help address many of the challenges associated with food loss. By one estimate, developing countries could save 144 million tons of food annually if they reached the same level of food cold chain (in terms of refrigeration equipment) as developed countries (IIF/IIR 2020a). However, improving the level of refrigeration equipment alone is not enough to address food losses: market connectivity is also key to ensure that the food being produced reaches consumers. For example, in India, a pilot cold chain project to supply kinnow fruit using precooling and aggregation helped reduce kinnow losses by 76 per cent while also lowering emissions (Box 3).

Box 3. Benefits of a cold chain: Kinnow pilot study in India

Kinnow is a seasonal, high-yield and low-cost mandarin-variety fruit produced in the western Punjab area of India. However, because of the lack of suitable cold chain facilities in the region, the fruit was only sold locally or in nearby states, typically from January to mid-March. After catering to this limited demand, large quantities were left unharvested or discarded every season. The existing cold store was used as temporary storage without any precooling or use of reefer transport, bringing less-than-expected benefits and no change in the marketing of the produce. The demand for kinnow in India's southern and eastern states was untested, limiting market growth.

A pilot cold chain project to supply the fruit was developed in 2016-17 under India's National Centre for Cold-chain Development (NCCD) and executed with the support of Carrier Transicold, a global company that provides refrigerated transport. The project was implemented through Balaji Cold Stores – a kinnow farmer that traditionally marketed the fruit in northern India and now serves as an aggregator – as well as through local service providers. The participating farmers and aggregators funded all the operations for the project, without government subsidy. The Indian School of Business, Mohali was deployed to monitor and capture the study data.

For the pilot study, the local farmer-aggregator was persuaded to invest in a precooling packhouse and was also guided in its operations and in best practices. The four-month supply project was initiated in February 2016, with the precooled and packaged fruit stored in the available cold store, and a domestic reefer transport company hired to move the produce across 2,500 kilometres to a distant and untried market in Bengaluru, in southern India. NCCD also linked the wholesale traders operating in the terminal market for the project. For comparative study, the existing distribution of the fruit was also continued.

Multiple supplies to Bengaluru were carried out and studied, as the addition of precooling extended the selling period by several months, through May 2016. The project results showed that proper use of the cold chain not only extended the saleable life of the produce, but also helped expand its selling radius. The fruit was readily accepted by consumers in the new market, which valued it at a higher price than in traditional north Indian markets. Connectivity resulted in faster cash flows for farmers, instead of having to store inventories while awaiting sales in the local market. Through the project, food losses declined 76 per cent, adding to higher returns for farmers, and system-wide greenhouse gas emissions fell 16 per cent, even using diesel-powered transport refrigeration units and grid-based electricity (Fig. 3).

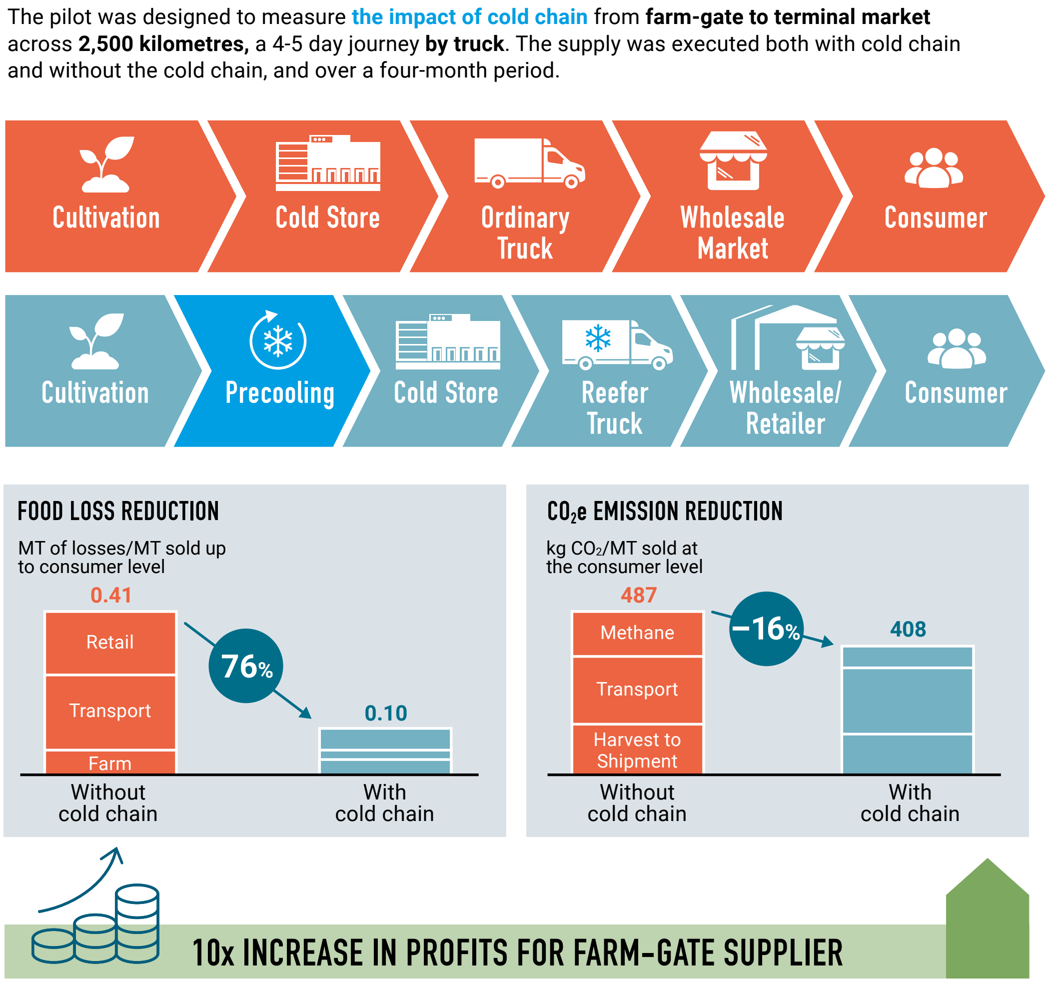
In the subsequent (2017) season, the producing zone saw 9 new packhouses with precoolers, where none existed before, and dispatched more than 350 reefer truck loads across India and also connected with export markets. Furthermore, farm productivity was rejuvenated, and on average farmers reported a four-fold increase in selling volumes with a multiplier effect in earnings, thanks to the cold chain.

Source: P. Kohli, personal communication, August 2021

2.3 CURRENT STATUS AND FUTURE DEMAND FOR FOOD COLD CHAINS

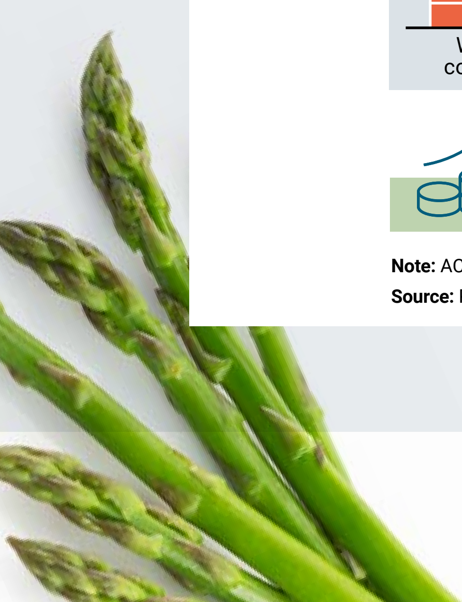
The global food cold chain capacity has been growing in recent decades. The Global Cold Chain Alliance (GCCA) estimates that the world's refrigerated warehouse capacity grew 16.7 per cent between 2018 and 2020, to 719 million cubic metres, with most of the increase occurring in North America and China (GCCA 2020). This growth is distributed unevenly, and many developing countries need substantial additional capacity to meet their cold chain needs. While the average cold storage capacity in North America, Western Europe and Oceania is around 200 cubic metres per 1,000 inhabitants, in the least developed countries it averages only around 20 cubic metres per 1,000 inhabitants, or even less (IIF/IIR 2021).

Figure 3. Impacts of a pilot cold chain project in India



Note: AC = air conditioning

Source: Pawanexh Kohli 2017



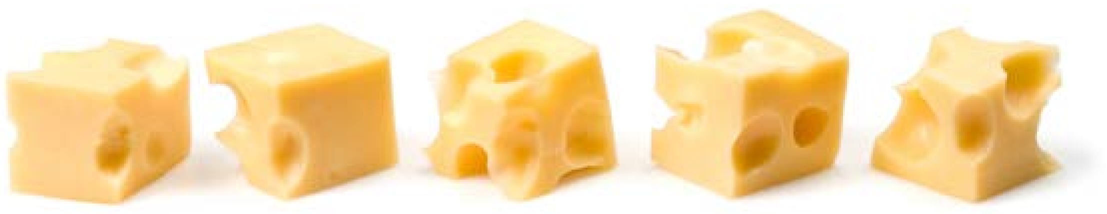
Beyond cold storage, food cold chains also require other infrastructure, such as refrigerated transport. For example, the GCCA reports that while India has the world's largest capacity of refrigerated warehousing[4] (Salin 2018), it is seriously lacking the means to transport this cooled food. The National Centre for Cold-chain Development of India (NCCD) estimated that India had less than 15 per cent of the refrigerated trucks it needed in 2015, impeding connectivity between producers and markets. While the country's fleet has since risen to around 19,000,[5] this is still less than a third of what the NCCD has proposed is required to meet India's food cooling needs[6] (NCCD 2015; University of Birmingham 2017).

The NCCD study also found that food aggregation hubs, located at or near farms to serve as distribution logistics platforms, were also limited in India.[7] To supply existing domestic consumption in a sustainable way through the food cold chain, the country would need to develop around 69,000 packhouses with precooling facilities. Without these "first-mile" facilities built close to the farm gate, investments in other components of the food cold chain, such as refrigerated trucks and cold rooms, become inefficient.

Aggregation and transport facilities at the farm gate are key to expanding the market reach of farmers, contributing to both higher incomes and increased farm productivity. In India, the focus has traditionally been on creating local markets at the farm gate, and farmer incomes have depended mainly on the capacity of local buyers, most of them visitors on foot. In contrast, developing aggregation facilities near farms, with transport services to expand the reach of farmers to the larger national market and into exports, would enable farmers to directly access and capture a larger share of consumption (Box 3). Expanded market connectivity would then make it more viable for farmers to increase the productivity of their fields. Based on this reasoning, an inter-ministerial Committee on Doubling Farmers' Income has recommended this approach to India's cold chain development (Ministry of Agriculture & Farmers Welfare 2017).

Overall, food cold chains are expected to expand significantly over the coming decades to cope with the increasing demand for perishable food products as well as to address current unmet needs for cold chain. For example, based on cooling sales, industrial refrigeration and transport refrigeration are projected to be the fastest growing sub-sectors within the cooling sector globally, with average annual growth rates of 5.1 per cent and 4.8 per cent, respectively, between 2018 and 2030 (Fig. 4) (Economist Intelligence Unit 2019). This is due mainly to expected growth in industrial production and in cold chain capacity, to meet the cooling demand both for food and for temperature-sensitive pharmaceutical products such as vaccines.

However, analysis led by the University of Birmingham suggests that growth in the global food cold chain will need to be dramatically higher than the current estimates to deliver cooling for all who need it, and therefore to meet the targets of the UN Sustainable Development Goals (Box 4). Many developing countries need substantial additional capacity at all stages, including the systems and processes needed to ensure uninterrupted connectivity from farm to fork, as well as the skills required to install and maintain cooling equipment.



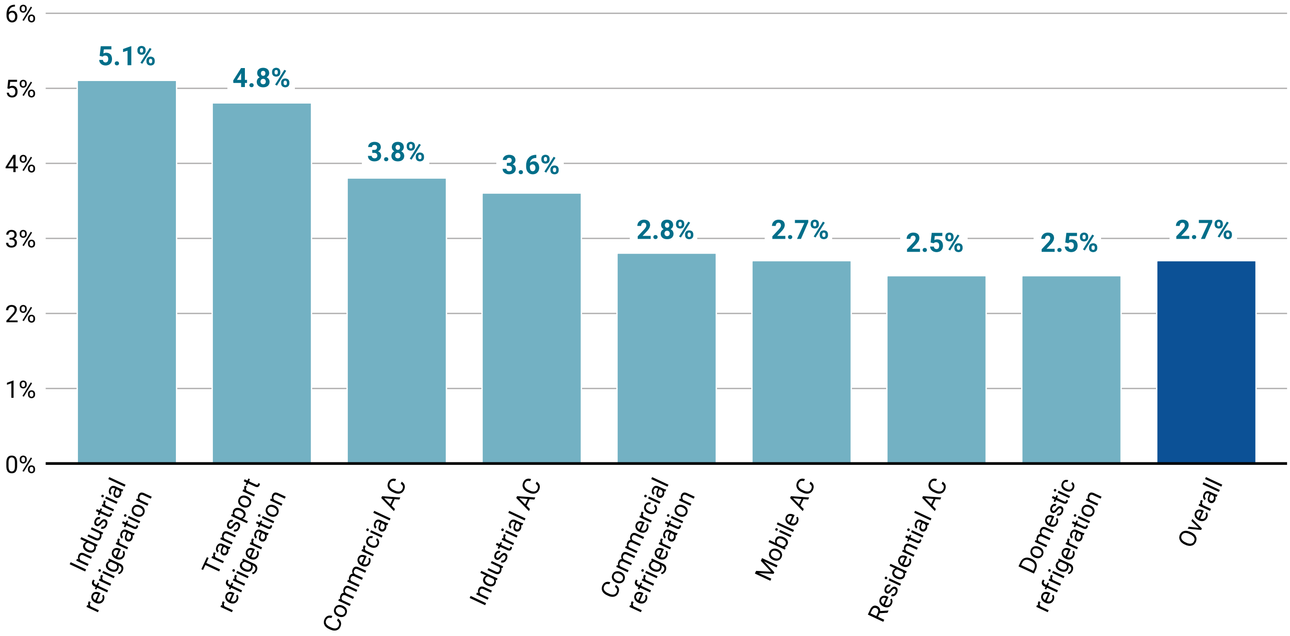
4 In 2018, among the countries included in the GCCA database, India had 150 million cubic metres of refrigerated warehouses, followed by the United States with 131 million cubic metres and China with 105 million cubic metres (Salin 2018).

5 For comparison, the United Kingdom has around 84,000 refrigerated vehicles for a country that is far smaller geographically and has 5 per cent of the population of India. The European Union has around 1 million refrigerated vehicles (Dearman 2015), while the global fleet totals an estimated 5 million refrigerated vehicles (IIF/IIR 2019).

6 The NCCD estimates that the actual number required is three times larger, or closer to 180,000 vehicles, based on a linear assessment of return loads.

7 Notably, India has more than 170,000 milk aggregation points or pooling points, which allowed it to produce and distribute more than 200 million tons of milk in 2020-21, sourced primarily from small farmers. The milk cold chain, starting at village-level pooling points, has made India the global leader in milk with minimal losses in the supply chain.

Figure 4. Average annual growth in cooling sales by sub-sector, 2018-2020



Source: Economist Intelligence Unit 2019

Note: AC = air conditioning

Box 4. Delivering "cooling for all"

Despite the large-scale increase in cooling provision projected to take place in the next two decades, universal access to cooling is unlikely to be a reality at that time. This has important ramifications globally, as cooling is critical to ensuring access to nutritious food, safe medicines, and vaccines while enhancing productivity and comfort at home, school and work – all which are fundamental to achieving many of the SDGs.

The University of Birmingham report *A Cool World: Defining the Energy Conundrum of Cooling for All* (Peters 2018a) estimates that providing "cooling for all" who need it by 2050 would require 14 billion* active cooling appliances worldwide, or 3.8 times as many as are in use today. For the cold chain specifically, this means nearly 4.5 billion new pieces of refrigeration equipment, including domestic, commercial and industrial refrigerators** as well as transport refrigeration units (for trucks, containers, etc.). This is up sharply from the 1.7 billion estimated in 2018.

* Projections are based on the assumptions that: 1) refrigeration equipment penetrations globally converge to those experienced in the developed world today by 2050, and 2) air-conditioning is made available to all populations exposed to more than 2,000 cooling degree days per year (the number of degrees that a day's average temperature is above 21° C in this instance, multiplied by the number of days per year).

** Commercial refrigeration relates to refrigeration systems deployed in retail and restaurant premises, whereas industrial refrigeration relates to food processing and upstream distribution channels.

Source: Professor Toby Peters and Dr. Leyla Sayin

2.4 DRIVERS OF FOOD COLD CHAIN GROWTH

The growth in demand for food cold chains worldwide is influenced by a broad range of factors. These include, among others, population growth and urbanization, rising incomes, climate change, global food trade and changes in shopping patterns and food preferences, as discussed in the following sections.

Population growth and urbanization

The global population was estimated to increase 1 per cent in 2020, with many regions experiencing growth at double or triple this median rate (UN 2019). Food production is set to rise to feed the projected global population of 9.7 billion in 2050 and to close the large gap between food supply and demand relative to 2010 (UN 2019; WRI 2019). Higher food production will increase the need for food cold chains, which are critical to translate production at the source into supply at the demand end.

Meanwhile, the share of the world's population living in cities is expected to rise from 55 per cent in 2018 to 68 per cent by 2050 (UN Department of Economic and Social Affairs 2018), with much of this growth occurring in developing countries. This means that more people will live farther from food sources, and, simultaneously, food producers will be pushed farther from the demand due to loss of agricultural land caused by urban expansion. This will result in greater demand for robust cold chain logistics, with perishable products needing to travel greater distances. Equally, there will be greater demand for refrigeration at urban retail and hospitality outlets to meet the urban food demand.

Growing incomes and health, safety and environmental concerns

Growing middle-class (and higher) income levels will potentially result in greater food consumption. Combined with growing health, safety and environmental concerns, this will lead to changes in dietary patterns, with consumers demanding higher-quality, fresh and organic produce. This will inevitably increase the demand for cold chains. For example, global consumption of meat proteins is projected to grow 14 per cent by 2030 compared to the 2018-2020 average (Organisation for Economic Co-operation and Development [OECD] 2021). Similarly, the share of fresh dairy products in world food consumption is expected to rise over the coming decade, with substantial increases in India, Pakistan and Africa (OECD 2021).

Climate change

As the global mean temperature continues to rise, projections point to increases in the intensity and frequency of heat extremes, including heatwaves (Masson-Delmotte *et al.* 2021). Rising temperatures will increase the demand for refrigeration. Moreover, agricultural production is highly vulnerable to the impacts of climate change. Increasing mean temperatures and extreme weather events such as floods, heavy rainfall, wind and storms can greatly affect food production capabilities (Ministry of Environment of Rwanda 2018), putting more emphasis on the need to reduce food loss and waste through increased refrigeration. Climate change-induced extreme weather events may also stress logistics and transport links and increase the demand for emergency cold storage in affected areas.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Increasing temperatures lead to high levels of discomfort and heat stress not only for humans, but also for animals. This can result in high livestock morbidity and mortality levels along with productivity loss and reduced reproduction rates, which also put strain on the food supply chain (Dash *et al.* 2016; Sejian *et al.* 2018). For example, multiple studies conducted in India suggest that heat stress can reduce milk production by between 5 per cent and 50 per cent (Belsare and Pandey 2008; National Dairy Development Board 2021).

Increasing global food trade

According to the FAO (2021b), food and agricultural exports grew 3.2 per cent between 2019 and 2020, an increase of nearly $52 billion, with developing countries accounting for around 40 per cent of this rise. In 2021, the value of global agricultural trade was expected to increase 8 per cent, to $137 billion (FAO 2021b). The United Kingdom imported 84 per cent of its fruits and 47 per cent of its vegetables in 2019 (Department for Environment, Food & Rural Affairs 2020). Meanwhile, in India, the Agricultural Export Policy, introduced in 2018, aims to double the country's agri-exports to $60 billion by 2022 and to reach $100 billion in the few years thereafter (Government of India 2018). This expansion in global food trade will lead to increased demand for international refrigerated transport.

Changing shopping patterns and preferences

The COVID-19 pandemic has significantly changed the operation of the food cold chain, with a dramatic increase in the demand for refrigeration. For example, in June 2020, Lineage Logistics, the world's largest temperature-controlled logistics provider, reported that more than 90 per cent of its cold-storage facilities in Europe were full (Jha and Ritchie 2021). Demand for domestic refrigerators and freezers also increased due to changed shopping trends and increased demand for frozen products. In France, sales of frozen products were 60 per cent higher in March 2020 than a year earlier (IIF/IIR 2020b). To meet this rising demand, many food processors have increased their freezing capabilities, such as blast freezing (Avis 2021).

The demand for fresh produce also increased in some regions after the start of COVID-19. In India, food retailers and online shops reported a surge in demand for fresh produce, which is considered to have higher nutritional value and immunological benefits. India's Ministry of Agriculture estimates that domestic demand for fruits and vegetables will reach 650 million tons by 2050 (PIB 2021). Surging demand for fresh produce was also reported in the United States in 2020 (Vegetable Growers News 2021).

During the pandemic, many consumers started to visit one large supermarket irregularly rather than the previous habit of purchasing food on demand from smaller supermarkets. Online grocery sales also boomed. In both Germany and Italy, online grocery sales doubled during the first year of the pandemic (Eley and McMorrow 2020). In the United Kingdom, online grocery spending among retired households increased 229 per cent between January 2020 and January 2021 (McKevitt 2021). In the United States, online food shopping doubled in March 2020, and 46 per cent of consumers said they would continue to shop online after the pandemic subsided (CBREUS 2021).

All of these trends will prompt food retailers to rethink their refrigeration strategies and potentially expand their storage and transport capacities and capabilities to accommodate changing consumer needs today and in the long term.


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2.5 ENVIRONMENTAL IMPACTS AND THE IMPLICATIONS OF BUSINESS AS USUAL

The food cold chain has implications for the global climate and the environment as well. Conventional food cold chains typically rely on fossil fuel energy sources and are both energy intensive and highly polluting. Business-as-usual deployment will have undesirable impacts by continuing to add significant greenhouse gas emissions and pollution, compromising broader economic, environmental, social, and political goals, targets and commitments. This is especially important given that, to achieve the ambitious Paris Agreement target of keeping global temperature rise below 1.5°C, global CO_2 emissions will need to be reduced to net zero by mid-century.

The emissions from the food cold chain equipment come from both indirect and direct sources.[8] Indirect emissions are related to the electricity used to power refrigeration equipment, and to the fuel used to operate refrigerated vehicles and generators. Direct emissions come from the leakage of refrigerant gases into the atmosphere.[9]

Mechanical refrigeration equipment uses electricity to operate. By one estimate, refrigeration in supermarkets accounts for up to 4 per cent of the total electricity use in developed countries (Environmental Investigation Agency [EIA] 2021a). Producing this electricity releases CO_2-equivalent emissions and contributes to global warming, especially if the electricity is generated from carbon-intensive fossil fuel sources. The fossil fuel (mainly diesel) generators typically used for off-grid applications also release emissions. During transport, both vehicle engines and transport refrigeration units contribute emissions related to fuel consumption. A transport refrigeration unit consumes up to 20 per cent of a refrigerated vehicle's diesel fuel (Liquid Air Energy Network 2014).

Meanwhile, the leakage of many common refrigerant gases into the atmosphere contributes directly to global warming.[10] This occurs during the operation and servicing of cooling equipment, as well as following disposal at the end of life. Refrigerant leakage has a significant impact on the total emissions from refrigeration, as some refrigerants that are widely used today have a high global warming potential[11] and are hundreds to thousands of times more potent than CO_2 (Dearman 2015; Ozone Secretariat 2018). In total, around 80 per cent of the greenhouse gas emissions from refrigeration, air-conditioning and heat pump systems is associated with indirect emissions from energy use, whereas 20 per cent is associated with direct emissions from refrigerant use (Peters 2018a; Ozone Secretariat 2021a).

In addition to contributing to global warming, the leakage of some refrigerants causes ozone depletion.[12] Under the 1987 Montreal Protocol, ozone-depleting substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) have been mostly phased out globally[13] (United Nations Environment Programme [UNEP] 2018). Meanwhile, hydrofluorocarbons (HFCs), developed as substitutes for HCFCs, have zero ozone-depleting potential, but some HFCs have very high GWPs. Today's cooling market relies on around 16 pure HFCs and 30 blends, with GWPs ranging from under 100 to close to 15,000. R-404A, a common blend[14] used in medium- and low-temperature refrigeration applications, especially in the food retail and transport sectors, has a high GWP of 3,920 (UNEP 2020a; UNEP 2022).

8 TEWI (total equivalent warming impact) is a measurement for refrigeration that includes both direct emissions from refrigerant leaks and indirect emissions from energy consumption.

9 Even with the best systems, there will be some unavoidable refrigerant leakage.

10 The refrigerants can also impact indirect greenhouse gas emissions, as they may affect the energy efficiency performance of equipment.

11 Direct emissions are weighted according to the global warming potential (GWP) of a refrigerant and are measured in CO_2 equivalents. The GWP of a refrigerant is the total contribution to global warming resulting from the emission of one unit of the refrigerant relative to one unit of CO_2 with a GWP of 1.

12 The ozone depletion potential (ODP) of a refrigerant refers to the amount of ozone depletion the refrigerant can cause compared to a similar amount of trichlorofluoromethane (CFC-11) with an ODP of 1. CFC-11 was the first widely used refrigerant (Papasavva and Moomaw 2014).

13 HCFCs were phased out in developed countries in 2020, but up to 0.5 per cent of base-level consumption can be used from 2020 until 2030 for servicing existing refrigeration and air-conditioning equipment. Developing countries are aiming for a complete phase-out by 2030, but up to 2.5 per cent of base-level consumption can be used until 2040 for servicing existing equipment, subject to review in 2025.

14 A blend of R-125, R-143a and R-134a (UNEP 2022).

HFCs are among the fastest growing sources of greenhouse gas emissions due to the increasing global demand for cooling and refrigeration across the domestic, commercial, industrial and transport sectors (North American Sustainable Refrigeration Council 2021). Cooling and refrigeration accounts for an estimated 35 per cent of total HFC consumption in the cooling sector (UNEP 2020a). Studies suggest that keeping products cold during cold chain transport accounted for 7 per cent of global HFC consumption in 2010, which represents 4 per cent of the total global warming impact of moving all freight (including non-refrigerated transport) (US Environmental Protection Agency 2011). In the United States, refrigerants used in commercial refrigeration systems are responsible for around 28 per cent of domestic HFC emissions (Eilperin and Butler 2021).

To address this issue, the Kigali Amendment to the Montreal Protocol, which entered into force in January 2019, calls for the phase-down of HFCs by cutting their production and consumption, targeting a reduction of more than 80 per cent by 2047 compared to baselines. This HFC phase-down could avoid up to 0.4°C of global warming by 2100 (UNEP 2020a). Under the European Union's F-gas legislation, the use of refrigerants with a GWP of 2,500 and above, such as R-404A, was banned in stationary refrigeration applications for new equipment and servicing as of 1 January 2020.

Available data suggest that, altogether, food cold chain equipment contributed 261 million tons of CO_2-equivalent emissions in 2017 (IIF/IIR 2021). If this is added to the emissions from food loss and waste due to a lack of refrigeration (an estimated 1,004 million tons of CO_2-equivalent), then the combined total greenhouse gas emissions associated with the global food cold chain are an estimated 1,265 million tons of CO_2-equivalent, or around 4 per cent of total global greenhouse gas emissions (IIF/IIR 2021). However, more data are needed to accurately estimate greenhouse gas emissions from the food cold chain.

In the coming decades, emissions from food cold chain equipment are set to rise significantly as new cold chain capacity comes online in developing countries, especially if this infrastructure is delivered along conventional patterns. For example, in India, food cold chain emissions are expected to double by 2027 in the absence of any interventions (Kumar *et al.* 2018). Continued expansion of cold chains using conventional fossil fuel-based technologies can result in significantly higher cooling emissions, unnecessarily detracting from the benefits gained from reducing the emissions from food loss.

A 2018 study found that increased greenhouse gas emissions resulting from a cold chain expansion in sub-Saharan Africa similar to the historic cold chain expansion in North America or Europe could outweigh the emission savings from the reduced food loss (Heard and Miller 2019). Therefore, it is critical to calculate the expected increase in emissions from the planned expansion of the food cold chain, as well as the emission savings that is expected to be achieved from reduced food loss and waste due to this expansion, to avoid trade-offs between these two dimensions and to reach a net positive outcome. Moreover, it is important to implement all the measures that allow for reducing greenhouse gas emissions along the cold chain, including improved energy efficiency, the replacement of fossil fuel with renewable energy, and the reduction of refrigerant leakages.

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In addition to greenhouse gas emissions, the various stages of the food cold chain have other environmental impacts. For example, both preconditioning activities and food packaging result in large amounts of waste. Preconditioning activities – including cleaning, trimming, culling and washing food items before they are sorted and graded for packaging – result in dumps of organic material and effluents, with associated impacts on the environment. Typically, the dumps become pest breeding grounds, and the wash water contains chemical residues of fungicides and fertilizers that require safe disposal.

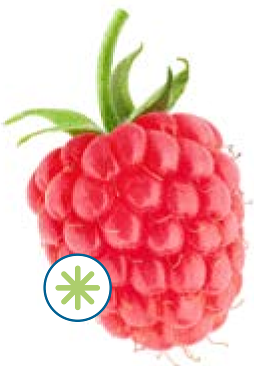
Packaging in the cold chain also leads to considerable waste. Packaging materials, which typically include plastics, wood, paper and foils, are used to make primary (individually packaged products, cartons, etc.), secondary (corrugated fibreboard boxes, plastic crates, etc.) and tertiary (bulk boxes, pallets, corner boards, shrink wraps, airbags, etc.) packages. These materials are often more robustly designed to withstand cold chain conditions such as high humidity and temperature dynamics, and the type of material used has a direct impact on food loss. Packaging is usually discarded after use and is a major contributor to urban landfills. Package labelling also involves elements specific for use in the cold chain, such as temperature-sensitive (thermo-chromic) inks and monitoring systems (paper and electronic data loggers).

Impacts also occur during the distribution stages of the food cold chain. Many forms of road transport already emit high levels of airborne pollutants, such as sulphur oxides, nitrogen oxides and particulate matter, often exceeding limits set by the World Health Organization. Refrigeration units add to this impact: by one estimate, a trailered transport refrigeration unit can emit 6 times as much nitrogen oxide and 29 times as much particulate matter as the modern Euro VI truck propulsion engine that pulls it (Dearman 2015). Yet regulations and standards for transport refrigeration units are often underdeveloped or not well applied. In general, data on the wide-ranging environmental impacts of cold chain activities remain scarce.

Given the expected growth in food cold chains globally, a business-as-usual approach to future development will exacerbate climate change and other sustainability challenges, with potentially long-term consequences. This poses a massive threat to achieving the world's climate and sustainable development goals. In developed countries, where emissions from cold chain equipment are already significant, sustainable cold chain development with minimal environmental impact is essential to bend the emissions curve. Meanwhile, in developing countries that already face energy insecurity, avoiding significant increases in carbon emissions through the use of clean energy is important to avoid putting added pressure on already strained energy systems, and to optimize the additional investment in energy infrastructure.

03 SUSTAINABLE FOOD COLD CHAINS

The food cold chain is critical to breaking millions of people out of the vicious cycle of hunger and poverty and meeting the challenge of feeding an additional 2 billion people by 2050. However, just as important is finding ways to achieve this sustainably, within the limits of our planet, while adapting to climate change and building resilience. Hence, there is an urgent need to shift towards sustainable food cold chains.



3.1 WHAT ARE SUSTAINABLE FOOD COLD CHAINS?

In the context of cold chain development, the term "sustainability" is often used in an undiscerning and loose manner. The focus tends to be on individual components of cold chain provision, with the decision criteria narrowly focused on steps such as change of refrigerants, measuring energy efficiency, quantifying savings on energy bills and using these bottom-line improvements as the basis when evaluating the return on investment. By themselves, these are but a factor of the larger value that accrues from business enablement and the actual revenue generated from using the food cold chain. The broader economic and societal benefits of access to cooling are typically treated as a "soft win", rather than as the core driver for providing cold chain services. Prioritizing sustainable food cold chains can help address this challenge.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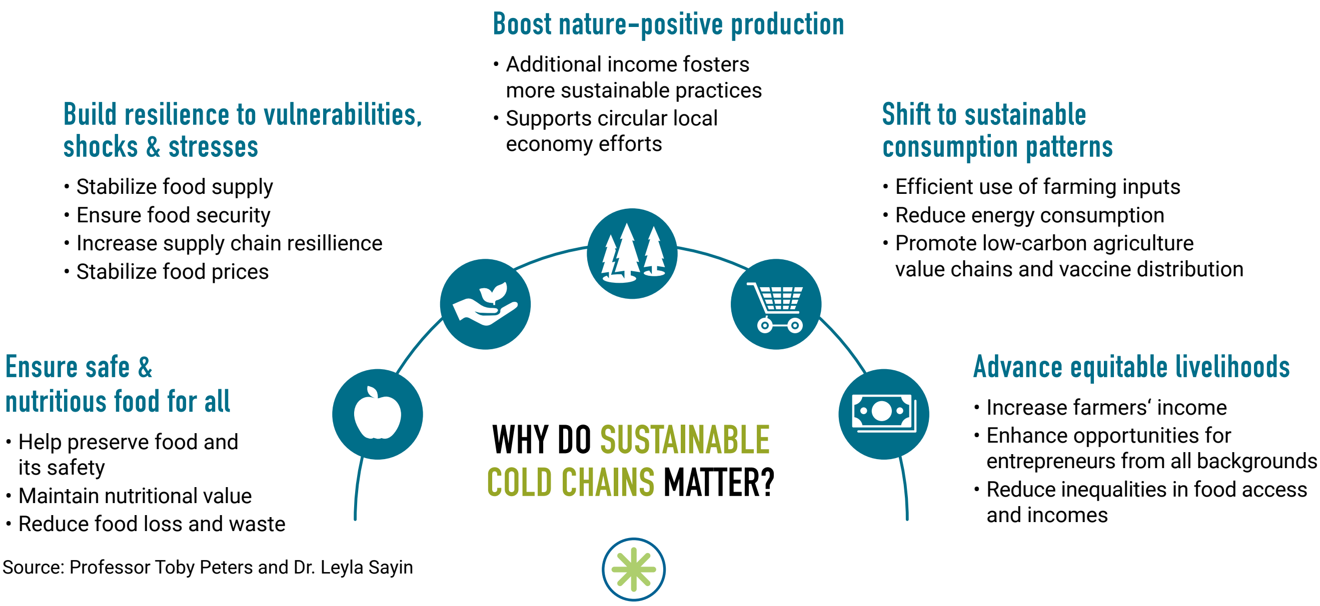
In general, there is limited understanding about what an economically, environmentally and socially sustainable food cold chain system should look like, especially in the context of future needs and innovations (e.g., electric vehicles, blockchains, drones, e-commerce, etc.). Delivering a sustainable food cold chain requires thinking beyond the specific refrigeration equipment deployed or the energy sources used, and also looking at aspects that concern the other activities, practices and missed opportunities in the cold chain business ecosystem. Realizing a truly sustainable and resilient food cold chain demands understanding, quantifying and valuing the broader and potentially strategic impacts of cooling, with their linkages to broader climate and development goals, taking into account poor, disadvantaged, and marginalized food producers and their communities, including women and youth.

Ultimately, there could be far-reaching social, economic and environmental consequences from rushing to deploy technologies and infrastructure without a comprehensive evaluation of the current and future scale as well as the nature of the demand for cold chain; the system complexities; its impact on energy use and associated climate risks; and its role in nutrition, health and livelihood sustainability. This is why sustainable food cold chains matter (Fig. 5).

3.2 SUSTAINABLE FOOD COLD CHAINS AND THE SDGS

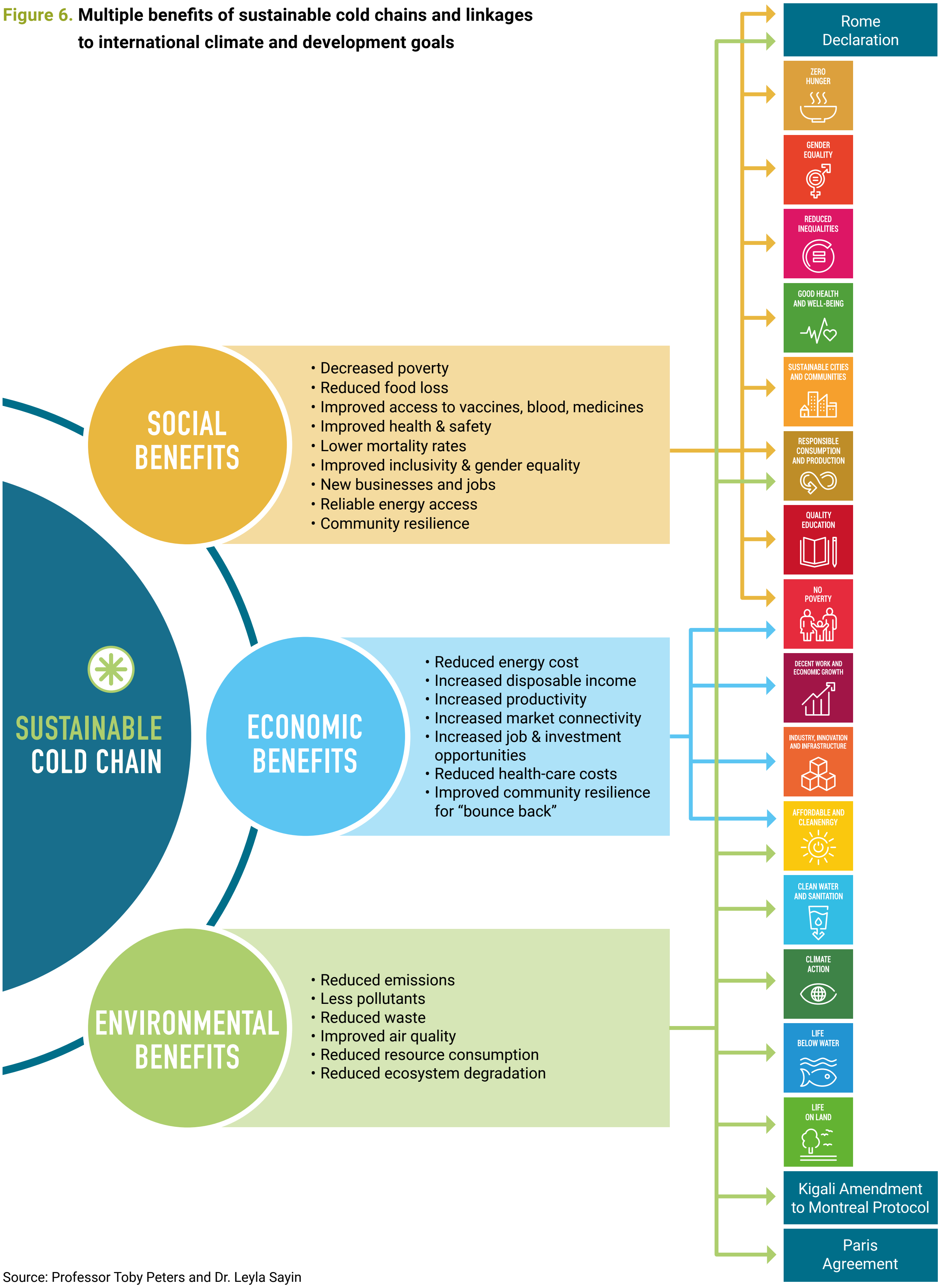
Sustainable food cold chains are key for improving human well-being, boosting economic growth, reducing greenhouse gas emissions, and increasing the resilience of food chain actors and the wider community. As such, establishing robust food cold chains continues to play an essential role in addressing many of the United Nations Sustainable Development Goals while balancing environmental, social and economic benefits (Fig. 6) (UN Department of Economic and Social Affairs 2020). Sustainable food cold chains are also critical to achieving the climate change targets of the Paris Agreement and the Montreal Protocol (especially its Kigali Amendment and the Rome Declaration).

Figure 5. Why do sustainable food cold chains matter?



Source: Professor Toby Peters and Dr. Leyla Sayin

Figure 6. Multiple benefits of sustainable cold chains and linkages to international climate and development goals



Source: Professor Toby Peters and Dr. Leyla Sayin

Done right, food cold chains can contribute to many of the SDGs. For example, they can:

- reduce food loss and waste, and thereby hunger, while raising the income of small farmers and fishers (SDG 1: No Poverty, SDG 2: Zero Hunger);
- reduce emissions from food loss and waste, and waste of agricultural inputs (SDG 6: Clean Water and Sanitation, SDG 12: Responsible Consumption and Production, SDG 13: Climate Action);
- increase market connectivity that would boost local economies and decrease poverty in rural agrarian communities (SDG 1: No Poverty, SDG 8: Decent Work and Economic Growth);
- create jobs and reduce the incentive to migrate to city slums (SDG 8: Decent Work and Economic Growth);
- help address gender barriers and broader inclusivity issues (SDG 5: Gender Inequality, SDG 10: Reduced Inequalities);
- reduce foodborne illnesses and protect the nutritional quality of food (SDG 3: Good Health and Well-being);
- improve air quality and reduce the level of other pollutants in the environment (SDG 3: Good Health and Well-being);
- reduce child labour by decreasing poverty, thereby preventing disruptions to education (SDG 4: Quality Education);
- improve access to clean energy and reduce energy costs through the provision of off-grid technology based on renewable energy and waste thermal energy resources, the use of passive cooling techniques and approaches, and thermal energy storage (SDG 7: Affordable and Clean Energy, SDG 13: Climate Action); and
- build resilience to unexpected external shocks, boosting people's ability to bounce back and recover from disruptions quickly as well as adapt to climate-related impacts and pandemics (SDG 11: Sustainable Cities and Communities).

3.3 SUSTAINABLE FOOD COLD CHAINS AND EQUITY

"Leaving no one behind" should sit at the core of sustainable food cold chain provision. This is because the social and economic costs of lack of access to cold chains fall disproportionately on poor, disadvantaged, and often marginalized farmers and fishers and their communities, as well as on women and girls. Efforts to expand and improve food cold chains, if not planned carefully to take into account equity issues, may further exacerbate inequities.

The estimated 500 million smallholder farmers globally account for a large proportion of the world's poor (World Bank 2016). They also comprise a large share of food producers: in Asia and sub-Saharan Africa, smallholder farmers contribute to 80 per cent of food produced (Business Call to Action 2021). With greater market connectivity through food cold chains, these producers can start growing higher-value produce. They can also gain flexibility and resilience with new market opportunities and grow produce that is better suited to new growing conditions as they emerge.

Gender inequality is another dimension that needs attention in the cold chain. Women comprise nearly half of the agricultural workforce in developing countries, ranging from 20 per cent in Latin America to almost 50 per cent in East and Southeast Asia and sub-Saharan Africa, hence playing a key role in feeding the world's surging population (FAO 2011). In sub-Saharan Africa, women farmers are responsible for 90 per cent of the processing and 80 per cent of the storage of food (Vercillo 2016). Yet women produce 20-30 per cent fewer yields than male farmers due to gender-related lack of access to agricultural credit, assets, inputs and services (World Bank 2017).

Thus, when devising interventions to reduce food loss, such as through the cold chain, it is critical to consider the role of women (in farms, in factories and at home) as well as their empowerment, access to resources and knowledge (Vercillo 2016; FAO and GIZ 2019). Ending gender-based inequality could increase the total agricultural output in developing countries by an estimated 2.5 to 4 per cent (World Bank 2017).

At the same time, women and girls are disproportionately affected by hunger, representing 60 per cent of the population facing chronic hunger (UN Women 2021). Women's power within a household and their control over resources tend to be related to the nutrition and weight of their children (Sustainable Energy for All [SEforALL] 2021). Access to refrigeration thus plays an important role in nutritious food security for both women and children. For a group of mothers surveyed in Benin, ownership of a refrigerator was linked to safer food preparation and better nutrition during a critical childhood growing stage (SEforALL 2021). Access to cooling technologies that help extend the life of perishable goods can enhance women's labour productivity, increasing the time available for engaging in productive activities outside the household (SEforALL 2021).

Similarly, women face an economic disadvantage and higher risk of poverty due to the greater likelihood of not having an income of their own and to the inequality in the division of unpaid care work (UN Women 2017). Expanding access to sustainable cold chains for women could help increase their agricultural yields, income, and food security, and reduce gender gaps. Examples of food cold chain efforts directed specifically to women include the "Cold women in Malaita" project in the Solomon Islands (Box 5), the EmPower project in Cambodia (Box 6) and Eja-Ice in Nigeria (Box 7).

To better identify these challenges and point to suitable solutions, additional gender-sensitive analysis is needed on the differing needs and constraints of men and women to ensure inclusive development of sustainable food cold chains.

Box 5. The "Cold women in Malaita" project: Solomon Islands

The "Cold women in Malaita' project, in the rural Solomon Islands, aims to provide solar-powered freezers to women who cook and sell fish for a living, thereby improving their marketing opportunities. Fishing is the primary income source for around 30 per cent of the country's population. Moreover, 80 per cent of inhabitants live in rural areas, and only 48 per cent have access to electricity. Therefore, improvements in the fishing cold chain can support development efforts within local rural communities.

The solar-powered chest freezers*, which have a capacity of around 200 litres, were donated to existing women's groups in the rural community of Malaita. In turn, these women offer temporary cold storage services for fish and other perishable food. Moreover, they can bring and store other frozen products such as chicken and meat from the capital city and sell them in the village. Thanks to this project, for the first time, refrigeration was available in the community. During the project's first year, the freezers stored around 1,000 kilograms of fish and were used by 487 people, enabling the women to generate enough income to cover all the expenses required by the freezers.

* Note that the freezers use the refrigerant HFC-134A, which has a high GWP of 1,430.

Source: FAO

Box 6. Renewable energy-based cold storage chain and women's participation in the Lors Thmey vegetable delivery system: EmPower project, Cambodia

Through the EmPower project, a joint initiative of UN Women and UNEP, two sets of mobile solar hybrid cold storage systems with capacities of 18 cubic metres each were to be installed in the first half of 2022 at the office of Lors Thmey in Cambodia's Takeo province and in the capital city of Phnom Penh, in addition to one cold truck. Lors Thmey has worked with women farmers in Takeo since 2013, providing technical training and selling agricultural inputs including vegetable seeds and fertilizer. Lors Thmey supports a cluster of contract farms and purchases vegetables from these farms at the collecting point of each cluster, which is normally operated by a Farmer Business Advisor. The project exclusively serves 54 women contract farms.

The main barriers facing the project are the high capital investment and fluctuating vegetable prices in the market. To address these challenges, UNEP is working with its partners to develop and test a financial mechanism comprising a subsidy and low interest rate. To minimize the price fluctuations, a seasonal planting plan should be developed to grow different types of vegetables based on the demand per season.

Source: UNEP

Box 7. Eja-Ice solar-powered freezer: Nigeria

Eja-Ice offers solar-powered freezers to women in the fisheries supply chain in Nigeria through a lease-to-own scheme to enable inclusion through asset acquisition. These assets give women a chance to trade sustainably, support their families and offer nutritional items such as frozen fish and chicken. Eja-Ice further helps women reduce their exposure to risks by providing 36 months of technical support and insurance coverage, including burglary, fire and credit life insurance.

Source: Y. Bilesanmi, Eja-Ice, personal communication, August 2021

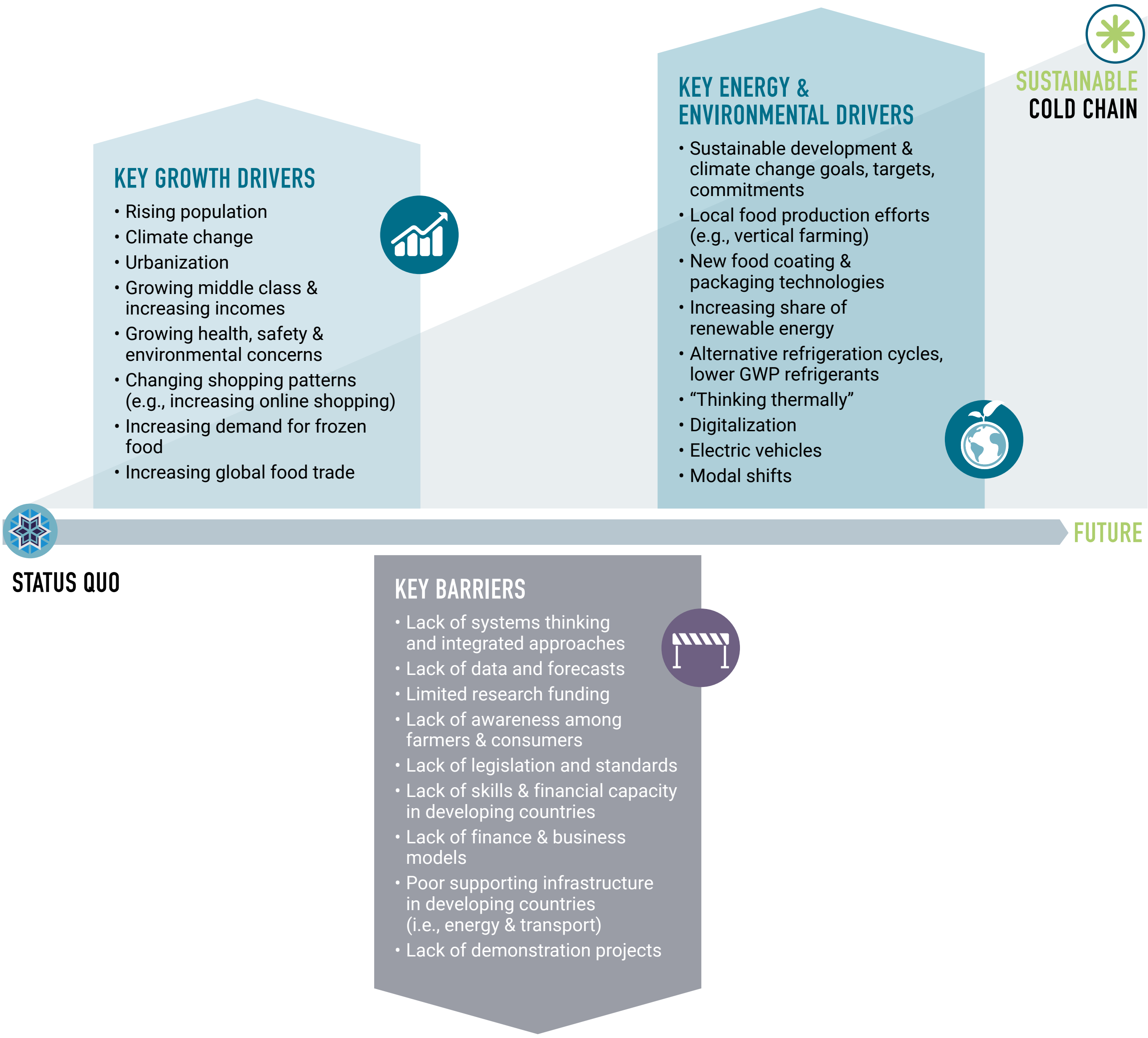
04 DESIGNING SUSTAINABLE FOOD COLD CHAINS

Designing sustainable food cold chains requires going beyond a view of the food cold chain as linear. One has to take an end-to-end systems approach, considering dynamic and interconnected relationships and feedback loops between processes as well as social, economic and environmental outcomes within the whole system. It is also important to use a future-oriented approach and understand how the cold chain's needs, requirements and technologies might evolve over time.

To this end, it is useful to understand the key energy and environmental drivers for sustainability in the food cold chain, complemented by the drivers for cold chain growth more generally (see discussion in section 2.4), and how these will shape cold chain demand and provision over the coming decades. It is also important to identify the key barriers to successfully delivering sustainable food cold chains to all (Fig. 7). These barriers, elaborated in section 4.2, will need to be addressed to facilitate sustainable expansion with minimum environmental impact while also achieving the SDGs and strengthening community and system resilience.

Already, a wide range of technologies, projects, finance and business models, local and international policies, and other efforts aim to address issues around sustainable food cold chain development. With an understanding of the main drivers and barriers for sustainable food cold chains, cold chain developers, governments, policymakers and financiers can identify the most cost-effective pathway for transitioning to a smarter, decarbonized, and resilient food cold chain system, as well as enable better cohesion across sectors to reduce the investment risk. Ultimately, there is a need for end-to-end system-level approaches to achieve a sustainable food cold chain over the long term.

Figure 7. Key drivers and barriers for sustainable food cold chains



Source: Professor Toby Peters and Dr. Leyla Sayin

4.1 ENERGY AND ENVIRONMENTAL DRIVERS OF SUSTAINABLE FOOD COLD CHAINS

Sustainability in the food cold chain is driven by numerous energy and environmental factors. These include emerging regulations, policies and initiatives spurred by increased awareness of the critical role of sustainable cold chains in achieving wider climate and sustainability goals; advanced design approaches and refrigeration technologies that have zero ozone layer and lower climate and resource impacts; shifts in transport modes; and other factors.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Sustainable development and climate change goals, targets and commitments

The importance of cooling and cold chains in delivering the SDGs and ambitious climate targets has been increasingly recognized globally. Many countries have been developing and implementing national cooling plans with support from the cooling community. These plans include roadmaps and timetables for achieving a sustainable cooling economy, involving short-term and long-term considerations on refrigerant transitions (HCFC phase-out and HFC phase-down), reducing cooling demand, enhanced minimum energy performance standards (MEPS) and goals for universal access to sustainable cooling.

As of 2021, 55 countries had committed to reduce their cooling emissions in either their enhanced Nationally Determined Contributions (NDCs) or long-term climate plans under the Paris Agreement; this is up from only 6 countries that included cooling in their NDCs in 2015 (Clean Cooling Collaborative 2021). The international community has also recognized the role of cold chains in food systems in the Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction through Sustainable Cold chain Management (Box 8), and in a 2019 UN Environment Assembly resolution (Box 9) (Ozone Secretariat 2021b). The Rome Declaration stresses “the importance of pursuing national action and international cooperation to promote the development of the cold chain, including by using sustainable and environmentally friendly refrigeration to reduce food loss”.

Increased awareness about food loss and waste and the associated environmental impacts have also led many businesses to put the issue on their agenda. For example, during the UN climate talks in Glasgow, Scotland, in 2021, the food retailers Tesco, Sainsbury’s, Waitrose, Co-op and M&S pledged to halve the environmental impact of food waste they produce by 2030 in the United Kingdom, working with WWF (Lee 2021).

Box 8. The Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction

The Montreal Protocol controls the production and consumption of ozone-depleting substances that are widely used in the refrigeration and cooling sector. Many of these are also potent greenhouse gases. A universally ratified multilateral environmental treaty, the Montreal Protocol helped phase out 99 per cent of these chemicals worldwide, and is often considered, in the words of former UN Secretary General Kofi Annan in 2003, "perhaps the single most successful international environmental agreement to date" (Ozone Secretariat 2009). The Montreal Protocol has also raised awareness of the need to develop energy-efficient solutions in the refrigeration and air-conditioning sector to address the demand for both cooling systems for human comfort and cold chains for food (and pharmaceutical) preservation.

The Kigali Amendment, which was adopted in 2016 and sets a clear schedule for phasing down HFCs globally, entered into force on 1 January 2019 and is expected to trigger global technological conversion efforts in several industrial sectors. Those sectors, which include commercial refrigeration and the cold chain sector more broadly, rely on refrigerant gases and thus will be affected by the ongoing efforts to phase out ozone-depleting substances and phase down HFCs.

For this reason, at the 31st Meeting of the Parties to the Montreal Protocol in Rome in 2019, the Government of Italy promoted in coordination with the Ozone Secretariat and the FAO the Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction through Sustainable Cold Chain Development. The Declaration, signed by around 84 Parties as of 2021, aims to highlight the role of the cold chain in implementing the 2030 Agenda for Sustainable Development and the achievement of the SDGs related to ending hunger and poverty, food security, improved nutrition, climate action, sustainable agriculture and fisheries, and health and well-being.

Parties that signed the Declaration, among other things, pledge to work on pursuing national action and international cooperation to promote the development of the cold chain, including by using sustainable and environmentally friendly refrigeration to reduce food loss, as well as on strengthening cooperation and coordination between governments, the institutions of the Montreal Protocol, UN specialized agencies, existing private and public initiatives, and all relevant stakeholders to exchange knowledge and promote innovation of energy-efficient solutions and technologies that reduce the use of substances controlled by the Montreal Protocol in the development of the cold chain.

The Declaration therefore represents a key milestone for global action in mainstreaming the promotion of cold chain sustainability in the context of global climate and sustainable development actions, which offers a guiding framework for all actors to address the issue at the domestic and global level.

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Source: UNEP and FAO

Box 9. UNEA-4 Resolution

The United Nations Environment Assembly (UNEA), the highest international environmental authoritative body, adopted in its fourth session, in March 2019, a resolution titled "Promoting sustainable practices and innovative solutions for curbing food loss and waste". The resolution calls on governments, industry, organizations and UN bodies to take several actions, including:

- Develop and share best practice regarding integrated, energy-efficient and safe cold chain solutions that bring value to farmers and producers, and introduce innovative post-harvest technologies that are consistent with international commitments regarding sustainable cooling technologies and logistics and transport of food products that can extend the shelf life of sensitive products.
- Promote applied research on
  - the impact of climate conditions on production, storage and transport, which leads to food loss and waste in a wide variety of environmental conditions, including in high-ambient-temperature countries;
  - innovative solutions to avoid losses and minimize the impact identified in the production chain; and
  - industry engagement to introduce appropriate energy-efficient refrigeration and other cold chain solutions for farmers, producers and small and medium-sized enterprises, including in post-harvest and processing facilities and transport.

Source: UNEP

Efforts to increase local food production

Increasing the amount of food produced locally can reduce a country's reliance on imports and ensure a more stable supply of food – a need that has been brought to the fore by the COVID-19 pandemic. Increased local production also results in shorter travel distances, which can lead to a reduction in cooling demand for transport and storage. According to one estimate, using the same amount of fuel, 5 kilograms of food can be transported 3,800 kilometres by ship, 2,400 kilometres by rail, 740 kilometres by truck and only 43 kilometres by air (Brodt and Feenstra 2007).

To boost local production, for example, the UK-based online supermarket Ocado has invested heavily in vertical farming (BBC News 2019; Baker and Laister 2021), a sector that is projected to grow from $3.6 billion in 2021 to $17.6 billion in 2028, a compound annual growth rate of 25 per cent (Fortune 2021). However, local production will likely not meet all demand, due to various factors, and food cold chain connectivity with areas better suited for food production will still be necessary.

New food coating and packaging technologies

New technologies can increase a food's shelf life in tandem with refrigeration, and in some cases reduce the need for refrigeration. For example, in Co-op stores in the United Kingdom, the fresh produce supplier Jepco has launched its Living Lettuce innovation, in which the whole head of lettuce comes with the root system intact, helping the lettuce last longer than traditional bagged salad leaves, with a shelf life of at least seven days (Cheshire 2021). Another example is the Apeel, a plant-derived edible coating made from lipids and glycerolipids that exist in the peels, seeds, and pulp of fruit and vegetables. Developed by Apeel Sciences, the coating creates a natural barrier that locks in moisture and reduces oxidation, and can extend shelf life by two times that of untreated produce (Apeel 2021).

Increasing the share of renewables in electricity generation

The renewable share of electricity generation has been increasing in many countries as part of decarbonization efforts. Globally, renewable power generation is increasing faster than overall power demand (International Renewable Energy Agency [IRENA] 2020), and solar photovoltaics and wind are becoming the cheapest sources of electricity in many regions (IRENA 2018). However, the share of modern renewable energy in global final energy consumption is still low, at 10 per cent, and has increased only slightly from 9.5 per cent in 2015 due to the simultaneous increase in energy consumption (IRENA 2020). In general, the growth of renewables will enable more of the cold chain to operate on non-fossil fuel electricity.

Thinking thermally

In many cases, the provision of cooling and heating could be achieved more effectively, efficiently and sometimes synergistically through the use of waste and/or wrong-time thermal energy resources and thermal energy storage rather than electricity and (chemical) batteries. Some retailers have adopted technology that captures the rejected heat from refrigeration systems for use in space heating and hot water in stores, providing energy and emission savings and leading to overall emission reductions. With the integration of thermal energy storage, heat is stored during times of high refrigeration loads and low heating requirements, and the stored heat is then made available for use during periods of high heating demand. A study suggests that an integrated heating and cooling system with thermal storage can lead to decreases in annual greenhouse gas emissions of up to 13 per cent and decreases in energy consumption of up to 18 per cent, compared to heat recovery with a gas boiler system (Maouris *et al.* 2020). Cold energy can also be stored to avoid peak demand charges and ensure uninterrupted supply during outages.

Adopting alternative refrigeration cycles

The vapour compression cycle is still the most widely applied method of refrigeration. However, a wide range of alternatives are available (Box 10). For example, sorption refrigeration cycles are thermally driven and offer flexibility in terms of energy sources (Box 11). Scientists and engineers have been exploring alternatives, such as magnetic or thermo-acoustic refrigeration. While they show promise, more research and development is needed for these technologies to prove a realistic alternative to conventional vapour compression systems.

Box 10. New Leaf Dynamic Technologies Private Limited: GreenCHILL – biomass-powered cold rooms

Rather than relying on electricity or fossil fuels, GreenCHILL uses biomass to generate cooling using an adsorption refrigeration technology that uses a solution of water and R-717 (ammonia) as a refrigerant with zero GWP. The adsorption cycle is powered by hot water, which is provided through a boiler unit that uses biomass for the heat source. The GreenCHILL system can be integrated with any standard industrial-grade 10-20 ton cold room, up to 150 ton capacity, that can be used as a cold storage, precooler, ripening chamber or milk chiller. GreenCHILL replaces a conventional direct expansion system and runs independently from grid electricity, solar or a diesel generator. With minimal moving parts, the system is silent and has very low maintenance requirements.

As of 2021, New Leaf had installed 800 tons of cold storage space, benefiting more than 5,000 farmers across India. This space serves as a marketing platform for perishable produce from farms, generating an additional income of $6,000 per installation annually. New Leaf has also trained more than 200 farmers in post-harvest management, with the aim of reducing post-harvest losses from more than 30 per cent currently to below 5 per cent. New Leaf also trains and employs local women and youth to manage the GreenCHILL operations daily, generating income for three persons per installation and empowering women engaged in the agriculture sector. One GreenCHILL system saves around 40 tons of greenhouse gas emissions per year by displacing the predominantly coal-powered grid with carbon-neutral locally available biomass. GreenCHILL provides savings of around 4,500 units of electricity per month for a 20 ton cold room.


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Source: A. Agarwal, New Leaf Dynamic Technologies (P) LTD, personal communication, August 2021

Box 11. Coldway Technologies – last-mile delivery of meal baskets with eco-friendly self-refrigerated containers

Coldway Technologies, a branch of Sofrigam group, develops and commercializes self-refrigerated containers using an innovative approach based on solid gas sorption technology that relies on a reversible thermo-chemical reaction between ammonia and a metallic salt. Thanks to this technology, no greenhouse gases are emitted while on refrigeration mode, and the refrigerant used has no impact on ozone depletion. Once the system is fully recharged, refrigeration and heating effects are produced in an autonomous mode, working as a thermal battery.

Coldway has mastered this phenomenon to obtain a silent and eco-friendly refrigeration solution for urban logistics that is both flexible and easy to operate. Since 2017, in the city of Paris, around 50 self-refrigerated containers have been deployed, each one mounted on an electric bike or electric vehicle, to deliver meal baskets mainly to the elderly. Every day, in each container, more than 20 kilograms of meals are delivered and must be maintained at a temperature of 4°C (+/- 2°C). The containers are ATP certified, and the system can endure many door openings during a working day, guaranteeing precise temperature regulation to ensure the food quality.

Source: D. Tadiotto, Coldway Technologies, personal communication, August 2021

Using zero-ODP and lower-GWP refrigerants and considering trade-offs

In response to the Kigali Amendment and driven by related regulations, sectors of the food chain in developed countries – such as retail, catering and domestic – are moving rapidly to low-GWP refrigerants. Many developing countries are still using ozone-depleting substances such as HCFC, which are supposed to be fully phased out by 2030; the phase-down schedule for HFCs under the Kigali Amendment starts later, from 2024. In an example of efforts to transition to lower-GWP refrigerants, Colombia[15] is developing a strategy roadmap to increase the inclusion of "ultra-low GWP" alternatives, as well as to improve national capacities in energy efficiency in the retail sub-sector, promoting the elimination of substances controlled under the Montreal Protocol and compliance with the Kigali Amendment (Box 12).

Such tailored national phase-out and phase-down strategies are developed and implemented in many developing countries that are eligible to receive financial and technical assistance from the Multilateral Fund for the Implementation of the Montreal Protocol.[16] In addition, the Multilateral Fund has funded several successful demonstration projects using natural refrigerants in developing countries, with the aim to support and accelerate the phase-out of HCFCs and the phase-down of HFCs (Boxes 13 and 14).

Box 12. National strategy to improve energy efficiency and the direct environmental impact of commercial refrigeration systems and equipment in Colombia's retail sub-sector

Colombia has designed a national strategy that aims to promote the long-term adoption (2021-2030) of technological measures that improve energy efficiency and reduce the direct environmental impact of commercial refrigeration systems and equipment used in the retail (supermarket) sub-sector. The strategy does not include air-conditioning systems.

The strategy document characterizes the demand for commercial refrigeration equipment and systems in the retail sector and provides technical analysis of the main models and configurations in use, according to their energy consumption and direct environmental impact (including emissions). It also provides information on alternatives and measures to reduce the direct and indirect impacts generated from the equipment and systems (e.g., new technologies with lower GWP refrigerants, good practices for operating equipment and systems, and environmentally sound management of end-of-life refrigerants/ systems).

15 As part of the Article 5 (developing countries) Group 1, Colombia is required to freeze HFC production and use in 2024, with an 80 per cent reduction by 2045.

16 The Multilateral Fund provides financial and technical assistance to countries operating under Article 5 of the Montreal Protocol (mainly developing countries) to help them comply with their obligations under the Protocol to phase out the use of ozone-depleting substances at an agreed schedule.

In addition, the strategy outlines emission reduction scenarios related to the implementation of alternatives and measures; education and training instruments relevant to the strategy; regulations, policies and financing alternatives for implementation of the strategy; a roadmap for implementation; and instruments or programmes to support the formulation of the strategy. The main barrier to implementing the strategy is identifying financing mechanisms that support the additional capital investment required to acquire and implement the technological measures that improve energy efficiency and reduce the direct environmental impact of commercial refrigeration systems and equipment. The main implementation challenges facing the country relate to the need to:

- strengthen the training and education of personnel to meet the new needs of the sector due to technological changes, good operating practices, maintenance and final disposal of the refrigeration circuits;
- expand the national certification capacity to support technicians and others in the technologies and measures that improve energy efficiency and reduce direct environmental impact;
- develop new standards of labour competence for the implementation of measures that improve energy efficiency and reduce direct environmental impact;
- encourage new specializations or technical careers in commercial refrigeration that include the installation, maintenance and operation of new equipment or systems with less impact (use of new refrigerants with zero or low heating potential) and greater energy efficiency;
- strengthen the national capacity for refrigerant gas recovery, recycling and regeneration and for environmentally sound management of end-of-life refrigeration systems;
- develop new lines of credit for the implementation of energy efficiency technologies in refrigeration;
- seek financing mechanisms for the implementation of alternatives, since many of these require a higher level of investment (e.g., participation in the carbon credit market for reducing greenhouse gas emissions);
- develop campaigns related to responsible consumption by consumers of the products and applications of the different services; and
- strengthen the research institutes in refrigeration and air conditioning to support the required evaluations of the new technologies to the climatic conditions of the country.

Among the lessons learned to date are:

1. The energy efficiency labelling programmes and the successful implementation of minimum energy performance standards (MEPS) for low-capacity commercial refrigeration equipment and systems are key elements to incentivize both direct and indirect emission reductions among the parties.
2. To support the analysis required for the selection of an alternative, and to reduce energy consumption in large-capacity centralized systems, it is necessary to consider the implementation of specific MEPS for commercial refrigeration systems, or to strengthen rational energy use programmes in the retail sub-sector.
3. Regulations focused on the sound management of refrigerant gases complement the reduction of the direct environmental impact generated during operation, and at the end of the life cycle of the commercial refrigeration equipment and systems.

Source: E. M. Dickson, H. C. Mariaca Orozco and :. M. Suarez Orozco, Ministerio de Ambiente y Desarrollo Sostenible – Colombia, personal communication, August 2021

Box 13. Demonstration project to replace the HCFC refrigerant R-22 with non-HFC alternatives in countries with high ambient temperatures: The first CO_2-refrigerated supermarket in the Middle East (Jordan)

With funding from the Climate and Clean Air Coalition, the United Nations Industrial Development Organization (UNIDO) implemented in 2018 a pilot project using natural refrigerants at the Al Salam supermarket in Amman, Jordan, in collaboration with the Ministry of Environment of Jordan and technology providers from Jordan and Italy. Under the project, the Middle East's very first trans-critical CO_2 refrigeration system in a supermarket was implemented. Through the full-scale replacement of the supermarket's existing installations that used R-22, the project demonstrated the feasibility of a CO_2 trans-critical system in retail refrigeration in a country with high ambient temperatures.

The aim of the project was to evaluate the performance and energy efficiency of systems using CO_2 as the working fluid, as an alternative to the R-22 refrigerant that is still often used in retail installations in many developing countries. The system, installed in January 2018, is a CO_2 trans-critical booster system with parallel compression. To ensure high efficiency even during the hottest months, the system integrates state-of-the-art ejector technology. It also features non-superheated evaporator technology for both chilled and frozen food cabinets and storage rooms. The waste heat from the system can be recovered for hot sanitary water supply, saving further energy overall.

Compared to the previous system, the trans-critical CO_2 refrigeration unit results in a reduction in annual electricity demand of 40,000 kWh, which corresponds to a CO_2 emission reduction of around 32 tons per year. The direct emission reduction with the replacement of R-22 is around 35 tons of CO_2 equivalent annually. The success of the system has enabled a better understanding of the applicability of the technology in countries with high ambient temperatures and has promoted innovation within the national industry.


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Source: UNIDO

Box 14. Demonstration project to introduce trans-critical CO_2 refrigeration technology in supermarkets in Argentina

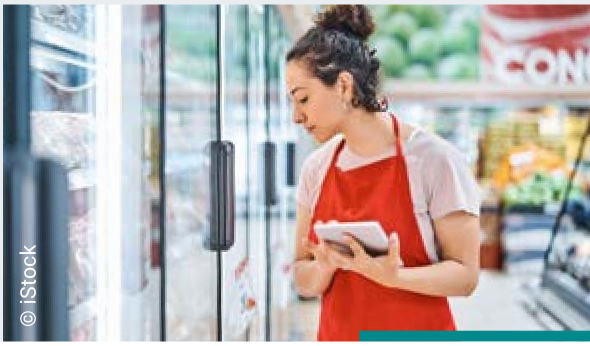
From 2010 to 2016, the five largest Argentine supermarket chains grew by 63 per cent (City of Buenos Aires 2011). During that period, R-22, an HCFC refrigerant with a high GWP of 1,760, was the most widely used refrigerant for retail food refrigeration systems, particularly in the supermarket sector. Given the sector's high reliance on R-22, the HCFC Phase-out Management Plan of Argentina prioritized phasing out HCFC refrigerant use in supermarkets.

In May 2016, the Executive Committee of the Multilateral Fund approved a project in Argentina to demonstrate the possibility of phasing out HCFCs by leapfrogging the HFC conversion step and introducing technologies based on natural refrigerants. The 30-month project, implemented by UNIDO with a budget of $527,169, aimed to evaluate the performance and energy efficiency of trans-critical CO_2 technology and to identify incentives and barriers related to an upgrade to this technology.

Following technical requirements provided by UNIDO and the National Ozone Unit of Argentina (OPROZ), a commercial refrigeration equipment manufacturing company, EPTA Argentina S.A., developed a CO_2 trans-critical system design with assistance from its design headquarters in Italy and the United Kingdom. The pilot project took place at a supermarket in the town of Lincoln, in Buenos Aires Province. The supermarket's two central refrigeration systems – one for low and one for medium temperatures – relied on R-22. In addition, a number of self-contained freezer units (islands and upright reach-in cabinets) operated using R-404A, which has an even higher GWP of 3,920.

During the first 11 months of the trial period, the CO_2 trans-critical system consumed 28 per cent less electricity than did the supermarket's pre-project baseline equipment (UNIDO 2018). In addition, the project led to significant direct emission reductions due to the much lower GWP and refrigerant leakage of the new system (Climate Transparency 2019). Based on these promising results, the recipient company, La Anónima, adopted trans-critical CO_2 as the default technology for its new branches and for refurbishing existing ones, where feasible. From 2016 to 2020, seven different companies adopted CO_2 trans-critical systems at a total of 13 supermarkets in Argentina. The same vendor also installed three such systems in Chile and nine in Ecuador from 2017 to 2020 (UNIDO 2018).

Source: UNIDO



However, the global warming potential of refrigerants is not the only parameter to consider in assessing the environmental impact of technologies. Other parameters influencing the efficiency of refrigeration systems include the thermophysical properties of refrigerants, the type of refrigeration cycle, the heat exchanger design, compressor selection and control strategies (Institute of Refrigeration 2021). In some applications and environments, the use of a natural refrigerant may in fact lead to higher energy consumption and total warming impact compared with a higher-GWP alternative. This was the case, for example, when the UK supermarket group ASDA tested the use of the natural refrigerant R-744 (CO_2) against HFO systems (Box 15).

Certain refrigerants may also present operational challenges such as flammability, toxicity and high pressure that could result in public safety risks if not handled properly. As such, the full range of technology alternatives and best-in-class systems must be explored to assess their optimality in terms of energy efficiency and emissions as well as operational use. It is also essential to ensure that the necessary skills for installation and maintenance are available.

Box 15. ASDA's exploration of natural refrigerants versus HFO systems: "Trial not error"

The UK supermarket group ASDA is exploring the opportunities and risks of achieving net zero emissions by 2040. To this end, ASDA engaged the consultancy firm WAVE Refrigeration to assess the greenhouse gas emissions and capital and operating expenditures of different refrigeration technologies being trialled by the company. The assessment revealed that ASDA's strategic direction of adopting HFO refrigerants (specifically, R-454A, which has a GWP of 237) resulted in the lowest annual emissions of all technologies considered. The assessment found that systems using a high-pressure natural refrigerant, R-744 (CO_2), resulted in inefficiencies that increased energy consumption when compared to HFO systems, thus resulting in higher emissions.

CO_2 refrigerant systems present an attractive alternative for ASDA because, to achieve its goal of net zero emissions, the company would need to capture or offset the direct emissions from HFO refrigerants. However, based on its studies, ASDA concluded that CO_2 systems currently come with higher capital and operational expenditures due to their higher costs for energy and maintenance compared to HFO systems.

Source: J. Bailey and B. Churchyard, Asda Stores Ltd, personal communication, August 2021

Digitalization

During the COVID-19 pandemic, even food cold chains in the developed world struggled with meeting consumer needs. Because cold chains worldwide tend to be fragmented, data sharing across stakeholders is limited, reducing flexibility and resilience. In response, digitalization across the cold chain has gained pace, with the objective of improving end-to-end visibility and transparency in order to improve the temperature management and traceability of products and to monitor and optimize cold chain equipment to prevent operational failures and ensure system performance.[17]

Digitalization also aids in modernizing inventory management in the cold chain. This facilitates processes such as FEFO (first-expire first-out), traceability and analytics to contribute to supply chain optimization, the Internet of Things and artificial intelligence to support integration and seamless operations, transparency that can ease power inequality in the supply chains, and more. For example, to reduce spoilage in the milk supply chain, the Kenya-based company Savanna Circuit Tech has developed a solar chilling-in-transit system along with a dairy management system enabled by artificial intelligence (Box 16).

Reducing journey times by using sophisticated route optimization technologies is another way to lower emissions from cold chain logistics as well as costs. For example, Routific, a route-planning software platform, helped delivery businesses around the world save 11,322 tons of greenhouse gas emissions in 2019, the equivalent of planting more than 500,000 trees (Routific Solutions Inc 2021). Yet the adoption of route optimization technologies is low even in many developed countries. For example, in the United Kingdom, less than 20 per cent of distribution businesses use route optimization (Cold Chain Federation 2021a).

Autonomous vehicles have also been getting attention, mainly in developed countries. For example, Ocado recently partnered with Oxbotica, a UK-based automated vehicle company, to integrate autonomous vehicles into its digitalized supply chain. The aim is to be able to better respond to peak delivery demands, reducing the cost-to-serve of its immediacy proposition and accelerating the shift to electrically powered vehicles, hence reducing the environmental impact (Ocado 2021).

17 Effective optimization, monitoring and maintenance can reduce total cooling greenhouse gas emissions by 13 per cent and deliver substantial energy savings of up to 20 per cent over the equipment lifespan (Kigali Cooling Efficiency Program 2018).

Box 16. Solar milk transport in Kenya

Savanna Circuit Tech, an innovation-centred company based in Kenya, focuses on “researching local problems and providing a comprehensive technological solution with a socio-economic impact”. After attributing spoilage in milk production to poor milk handling techniques by farmers, the company developed an affordable chilling-in-transit system to transport the milk safely. The system uses solar energy to keep the milk cool during transport from the farm to the collection centre. This enables farmers to minimize loss and spoilage and to ensure that revenue can be earned from the milk produced. The technology can also be used by cooperatives and milk processors.

The technology consists of an aluminium milk storage tank connected to a solar panel and mounted on a motorcycle. The solar panel produces electricity to cool the milk. The system also comes with a milk pH test kit and a weighing scale. The service requires the farmers to download an app, Maziwaplus, that keeps track of how much milk is sold by each farmer. The company also organizes the farmers into groups to operate the equipment at near-full capacity. Farmers notify the company when the milk needs to be transported to the bulkers – the companies that buy the milk collected from the various farmers, cool it and sell it to processors. After the Maziwaplus system operator arrives to collect the milk, it is weighed, tested for its pH value and cooled to 4°C for the duration of transit until it reaches the bulking stations. Each cooling unit has a capacity of 120 litres but can be customized to capacities of up to 1,000 litres. The farmers are paid via mobile money.

The company initially focused on direct sales to farmers, but the unit cost of the systems ($80) proved too high for the mostly low- and middle-income clients. As a result, the company settled on a lease business model, whereby the milk is transported to the bulkers for $0.003 per kilogram. The producer, motorcycle driver and bulker are connected via a mobile app that ensures inclusivity between the parties. Following commercialization of the cooling system, the company reported that farmers were able to increase their sale of milk by 40 per cent. In all, around 4,500 people have benefited, including direct beneficiaries such as milk producers and drivers, and indirect beneficiaries in new back-end jobs such as cleaning of the cooling units after milk delivery.

The company is active in two of four target regions in Kenya. A key challenge it faces is access to finance to expand the operation to other parts of the country. Additionally, given that the markets are characterized by high levels of illiteracy, the company is focusing on making the technology as simple and easy-to-use as possible by involving farmers in its development. The current scaling capacity is dependent on the company’s profits, which allows it to add a maximum of two or three units per month. However, the company intends to expand its operations to other African countries, especially Rwanda, Zambia and Uganda due to similarities in the dairy value chain.

Source: S. Mettenleiter and V. Torres-Toledo, SelfChill, personal communication, August 2021

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Electric vehicles

Electric vehicles will play a critical role in reducing emissions from refrigerated transport, and both the technology and the required infrastructure are rapidly expanding in the developed world. For example, UK-based supermarket Tesco has pledged to make its home-delivery fleet fully electric by 2028 as part of a commitment to reach net zero emissions by 2035, and has already deployed 30 electric delivery vans in Greater London. Tesco is also rolling out 2,400 charging points for customers across its stores (Commercial Fleet 2020). Meanwhile, Waitrose is to become the first supermarket in the United Kingdom to trial a fleet of electric home delivery vans that can be charged wirelessly by parking over a recharge plate (Box 17).

Modal shifts in transport

A shift in cooling transport technologies away from high-emission modes can result in a much lower environmental impact. For example, the Zipline drone delivery service has been successfully delivering medical supplies by aerial drone from its distribution centres to rural communities in Rwanda since 2016 and in Ghana since 2019. Zipline currently delivers more than 65 per cent of Rwanda's blood supply outside of Kigali, and in 2019, the company increased access to medical supplies for nearly 15 million people in Ghana (Ministry of Health of Ghana 2019; GAVI 2021). The UK-based food delivery company Just Eat has also begun offering drone deliveries (Best 2020; Food & Drink International 2020).

Box 17. Waitrose to trial wirelessly charged electric delivery vans in London

As part of its ambition to end fossil fuel use across its entire transport fleet by 2030, the UK-based supermarket chain Waitrose, working with Flexible Power Systems, had plans in early 2022 to trial a fleet of electric home delivery vans that can be charged wirelessly in London. The project builds upon the trial of wireless charging technology for light commercial vehicles in 2021 with the City of Edinburgh Council and Heriot-Watt University, funded by the UK Government's Office for Low-Emission Vehicles through its innovation agency, Innovate UK. The vans will all be based at Waitrose St. Katherine's Dock store, and Waitrose intends to expand it to other stores, if the trial is successful.

The trial involves seven Vauxhall Vivaro-e delivery vans, each fitted with a 75 kWh battery that delivers a range of up to 330 kilometres. The vans make use of a mixture of wireless and wired charging infrastructure. The vans are equipped with a slim charging pad on the underside, and they can be parked over a charging plate in the ground to begin charging. They can also be plugged in to charge overnight. The wireless charging kit is rated for 44 kW, whereas the wired chargers are 11 kW.

Wireless charging technology can provide many benefits in commercial applications, including faster starts to charging sessions, improved productivity of drivers and vehicle turnaround times, and reduced trip hazards and need for maintenance as there are no cables. Wireless chargers are also essential in the advent of autonomous vehicles that will have no driver to plug them in.

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Source: M. Ayres, Waitrose, personal communication, August 2021

4.2 KEY BARRIERS AND SOLUTIONS

Despite the many policies, technologies and other drivers spurring greater interest in sustainable cold chains, wide-ranging barriers to uptake exist. These barriers are discussed in the following sub-sections together with initiatives and solutions to address them

Lack of system-level thinking and an integrated approach

Integrated systems thinking to look more extensively and diversely at ways to meet cooling needs shows great promise. However, only limited tools to plan such systems exist, and no large-scale demonstrations have been completed. Delivering a systems approach requires stitching together cooling demand with cooling outcomes with the establishment of a common viewpoint on shared goals, parallel coordination across delivery partners combined with government and industry collaboration, while also deriving policy supported by finance to influence academic research and push innovation, new business models and adoption at scale.

However, the high diversity of the food cold chain – with a large number of cross-sectoral actors – makes communication and collaboration among stakeholders difficult. As a simple example, statistics reveal that in the United Kingdom, 28.6 per cent of vehicle-kilometres are running empty, and vehicles are utilized to only 63 per cent of their weight capacity (Greening *et al.* 2019). The problem of running empty can be reduced through greater collaboration among operators to minimize costs and greenhouse gas emissions from cold chain logistics.

As an example of system-based cold chain research design and roadmap projects, the ENOUGH and Zero Emission Cold Chain (ZECC) projects take a systems approach to food cold chain development in the United Kingdom, aiming to quantify and benchmark energy use and emissions and to create a roadmap for the UK food cold chain industry to identify opportunities to reduce emissions (Box 18).

Box 18. The ENOUGH and Zero Emission Cold Chain (ZECC) projects

The ENOUGH* project brings together 28 partners from 9 European Union countries, Norway, Turkey and the United Kingdom who have in-depth expertise across the whole food chain (refrigeration, cooking, baking, drying). During the project, the ENOUGH team will generate new information on emissions from the food chain, develop strategic roadmaps (technical, political and financial), develop digital tools and smart data analysis methods to quantify and benchmark energy use and emissions, and demonstrate technologies that are at a high technology readiness level.

During the four-year project, the team will implement innovative concepts and techniques, covering minimization of energy use and maximization of energy efficiency of cooling, freezing and heating processes, more widespread introduction of natural refrigerants, thermal storage techniques, energy demand/supply strategies, smart integration of cooling and heating, high-temperature heat pumps, adsorption/absorption cooling, heat-driven energy generation cycles, greater use of zero-carbon energy sources (including hydrogen, solar power and geothermal energy), efficient transport and packaging, alternative food supply chains and smart fridges.

In parallel, the ZECC project brings together diverse stakeholders – including leading interdisciplinary researchers working across the food cold chain sector and sustainable energy; government and global agencies; key industries and technology innovators; and cold chain customers from farmers to retailers – to provide fundamental new knowledge. The aim is to provide a whole-systems approach to redefine the cold chain architecture and map the opportunities available to reach net zero emissions by 2050, so as to deliver: 1) demand and climate adaptation; 2) resilience; and 3) decarbonization of the cold chain for the food industry, from farmer and fishers to consumers simultaneously.

* https://enough-emissions.eu
Source: K. N. Widell, SINTEF Ocean AS, personal communication, August 2021

Cooling and food cold chain needs are addressed only in a fragmented manner

Across the globe, cooling and food cold chain efforts tend to focus on individual technologies or interventions in silos. This leads to sub-optimal impact, to missed opportunities for sharing facilities, data and resources among actors, as well as to inefficient use of energy sources and a lack of connectivity. Many governments in developing countries continue to focus on deploying cold storage facilities rather than on integrated food cold chains that ensure connectivity from farm to fork. The concept of an “integrated cold chain” is misunderstood, tending to drive the combined or integrated ownership of required infrastructure assets, which is not practicable in the modern world.

Integration in the food cold chain implies shared operating procedures to manage the transactions between different entities, for streamlined and timely outcomes. The inherent challenges and important measures of the integrity of the food cold chain are about delivering food without any qualitative and quantitative losses and on time. Therefore, government policies need to be designed to encourage collaboration among the multiple asset owners and service providers. This can happen by moving away from capital subsidies alone to support growth targets in terms of quantity-based throughputs, market expansion and food loss mitigation.

Several countries offer examples of more-integrated policy approaches to cold chain. For example, after India’s National Centre for Cold-chain Development (NCCD) undertook the country’s first-ever cold chain assessment in 2015, identifying significant capacity gaps in reefer transport and modern packhouses, the country shifted its focus from blind investments in cold storage capacity to end-to-end cold chain that would enable seamless connectivity from source to destination. In Italy, the national law on tackling food loss and waste (Legge Gadda) supports integrated policy frameworks to promote food waste reduction and efficient cold chain development, including providing co-financing to procure the equipment necessary to conserve perishable food products (Box 19).

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Box 19. Integrated policy frameworks to promote food waste reduction and efficient cold chain development measures in Italy

Italy is strongly engaged in tackling food loss and waste and in showing leadership in this area in order to contribute to the UN's 2030 Agenda for Sustainable Development, in the framework of evolving strategies and provisions at the EU level. The country's commitment is enshrined in National Law No. 166/2016 (Legge Gadda) concerning the donation and distribution of food and pharmaceutical products for social solidarity purposes and reduction of waste. This legislation promotes waste recycling and reuse and contributes to the overall objectives of Italy's national programme for waste prevention.

The Law embeds several elements of the national plan against food waste (PINPAS), as it aims to facilitate the recovery and donation of food and pharmaceutical products. It defines food waste as the aggregate of still-edible food products discarded from the agri-food chain for commercial and aesthetic reasons or due to proximity to the expiration date.

The Law provides for an integrated policy scheme by establishing coordinated implementation and enforcement among relevant ministries. The Ministry of Ecological Transition, in coordination with the Ministry of Agriculture and Forestry and the Ministry of Health, is responsible for promoting information campaigns to incentivize the prevention of food waste. The relevant public administrations can utilize specific powers and instruments, including financial instruments and logistics measures, to promote initiatives targeted at the reuse of surpluses. This includes measures to promote the development and efficient streamlining of food cold chains.

In 2018, the Ministry of Ecological Transition launched a bid to co-finance integrated projects related to the recycling and reuse of surplus food throughout the agri-food chain, including during supply, transport, storage, conservation, processing and distribution. Critically this co-financing allowed for the provision of cold chain equipment to support food waste reduction, such as refrigerated vehicles and containers, blast chillers, thermal food trolleys, cold rooms, refrigerators and freezers. By enabling the adequate conservation of perishable fresh food products, such equipment supports the twin goals of reducing waste and maintaining quality while redistributing food to the poorest sectors of society.

Source: F. Mannoni, Ministry for Ecological Transition – Italy, personal communication, August 2021

Limited evidence-based data and forecasts

Data and forecasts on food cold chain demand and impacts remain limited. Rushing to deploy technologies and infrastructure without understanding the current and future scale, as well as the nature, of food cold chain demand, its impact on energy consumption and the associated climate risks could ultimately have far-reaching social, economic and environmental consequences. The availability of market information varies across the food cold chain, with some sectors providing little to no information. For example, the Chilled Food Association (2021) states: "There is no official collection of market data [for chilled food] either in the [United Kingdom, European Union] or internationally".

Similarly, there is limited evidence-based data on current food cold chain equipment stocks, equipment sales, refrigerant inventories and baseline greenhouse gas emissions. To help address this issue, a series of research programmes have been funded in the United Kingdom, Europe and developing markets, which include work packages to identify and describe an accurate and robust baseline for cold chain-specific emissions in representative countries. UNEP and the GFCCC also jointly initiated the Cold Chain Database Model to develop a complete database for the modelling of food cold chains (Box 20).

Box 20. The Cold Chain Database

The Global Food Cold Chain Council (GFCCC) and UNEP OzonAction are jointly developing a database model to quantify stocks, understand gaps, and project scenarios for different cold chain applications and processes. They are using a comprehensive assessment methodology and a thorough data collection approach that captures information about technologies, refrigerants, food loss, energy, economics and operation practices. The initiative marks the first formal step to help developing countries identify their cold chain baseline along with their consumption of relevant HCFCs, HFCs or other refrigerants. The model is designed to capture the details and specifics of each sub-sector. In addition to the 7 main sectors identified, 20-plus sub-sectors and 50-plus sub-sub-sectors are being classified within the database's scope of work to ensure the model's comprehensiveness and inclusiveness.

A detailed set of questionnaires, available in English, French and Spanish, was developed to facilitate the Stage I and Stage II data collection process. The data gathering activities cover five main topics:

1) Population and types of applications in each sub-sub-sector
2) Type, quantities and service practices of refrigerants used for each type of application
3) Basic energy consumption data
4) Information about food loss estimates and causes
5) Basic capital and operating expenditures (CAPEX/OPEX) of different types of facilities.

As of 2021, the project was in the initial phase of gathering information in Paraguay. Six food sub-sectors (farms, industries, logistics, supermarkets, services and end users) that require cooling were identified in the country. Data samples were collected from the food production sector as well as from industrial facilities, the food service sector and to a lesser extent other sub-sectors such as supermarkets, logistics and farms. The information was validated and complemented by local experts, and the data were evaluated and tested for the database and equivalent CO_2 emissions model by the GFCCC and UNEP OzonAction.

The preliminary results demonstrate the need to increase the level of sampling in some sectors. The data collection process revealed that many companies do not have quantified data on their cold and food processing systems and do not consider these issues to be of great relevance. Opportunities for improvement in the data collection were identified, and the pending data were expected to be released in early 2022 to generate representative samples that allow the development of a database with reliable information.

Source: UNEP and GFCCC

Projections on food cold chain demand and growth and their implications for energy systems and the climate are also not reliable. Often, projection efforts are based on analysis of historical equipment trends and thus fail to capture unmet needs as well as the influence of drivers (ranging from changes in consumer behaviour to transport modal shifts) on future food cold chain provision. As a starting point, countries must conduct robust needs-based assessments to better understand their food cold chain demand and current capacity and to inform the development of sustainable food cold chain roadmaps that also enable the SDG targets to be met. One example of such an approach is the Cooling for All Needs Assessment led by Sustainable Energy for All and Heriot-Watt University (Box 21).

Box 21. The Cooling for All Needs Assessment and National Cooling Action Plan Methodology

On World Ozone Day in 2019, UN Secretary-General António Guterres called upon countries to develop National Cooling Action Plans (NCAPs) "to deliver efficient and sustainable cooling and bring essential life-preserving services like vaccines and safe food to all people while driving climate action".

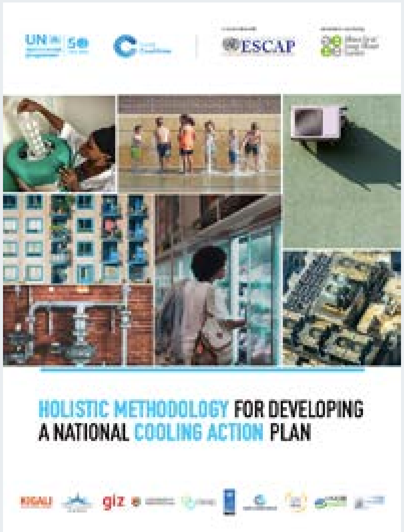
The Cooling for All Needs Assessment, developed by Heriot-Watt University and Sustainable Energy for All, is a peer-reviewed tool for governments, development institutions and non-governmental organizations to assess the full spectrum of cooling needs across buildings, cities, agriculture, and health, and to identify the policy, technology and finance measures to address those needs. This is a necessary first step to designing a sustainable and resilient cold chain system efficiently and effectively, ensuring minimal environmental and resource impact (Peters, Bing and Debhath 2020; Debnath *et al.* 2021).

Building on a needs assessment, many countries are developing NCAPs as a key policy tool to coordinate action on energy efficiency and the phase-down of HFCs, and to proactively address their growing cooling needs while reducing the climate impact of cooling practices, improving access to cooling and addressing several SDGs.

Responding to the call of the UN Secretary-General in 2019, the Cool Coalition brought together several NCAP pioneers to jointly support the creation of a comprehensive NCAP methodology that covers all relevant cooling sectors and end-uses (space cooling in buildings, mobile air conditioning, cold chain and refrigeration), and both met and unmet cooling needs. India's Cooling Action Plan was a major building block of this work because of its comprehensive approach and coverage of all sectors. Other important building blocks included the Cooling for All Needs Assessment and the 28 NCAPs developed or under development by various organizations participating in the Cool Coalition NCAP Working Group.

Currently being piloted in Cambodia and Indonesia, the methodology was prepared by the Alliance for an Energy Efficient Economy (AEEE), which helped develop the India Cooling Action Plan, under the guidance of UNEP Cool Coalition Secretariat and the UN Economic and Social Commission for Asia and the Pacific (ESCAP) in collaboration with the UN Development Programme, UNEP U4E and OzonAction, ESCAP, AEEE, the Clean Cooling Collaborative, the World Bank Group, Heriot-Watt University, Sustainable Energy for All, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the Energy China Foundation and Clasp.

The methodology can be found at https://coolcoalition.org/national-cooling-action-plan-methodology.



Source: UNEP Cool Coalition

Limited financial support for sustainable food cold chain development

Financial support for sustainable food cold chain development remains limited. For example, the European Union spent only 0.22 per cent of its total engineering research budget in 2018 on cooling research (Peters 2018b). Investment in research and development is critical not only to accelerate technological innovation, but also to make solutions more affordable and accessible to all. In general, food production has tended to receive more financial support than food cold chains and food loss reduction. However, governments and financial institutions increasingly recognize that intensifying food production alone is no longer a viable solution to respond to rising food demand and ensure food security.

In India, the government has been supporting food cold chain development through the private sector, entrepreneurs, and farmer organizations, by providing financial assistance and capacity support (Box 22). Thailand's Warehouse, Silo and Cold Storage Act, which came into force in 2015, aims

Box 22. India's policy efforts to develop a sustainable cold chain

India is the world's second largest producer of vegetables and fruits and among the top 10 producers of fish and meat (Peters, Kohli and Fox 2018). The Indian government, aware of the socio-economic value that cold chains add to its farming as well as urban populations, emphasizes developing cold chain systems as a policy, as is evident in its past five-year plans, ongoing missions, and dedicated agencies and departments. The government itself does not create the food cold chain but supports its development through the private sector, entrepreneurs and farmer organizations by way of financial assistance and capacity support.

The government operates various schemes, the major ones being the Mission for Integrated Development of Horticulture (for fresh produce) and Pradhan Mantri Kisan Sampada Yojana (for processing industry). The schemes are designed to subsidize the capital expenditure for cold chain with the aim of filling existing gaps in cold chain connectivity and fostering energy-efficient operations. A capital subsidy of 35 to 50 per cent is provisioned for cold chain infrastructure creation, which is extended for a variety of components such as modern packhouses, reefer vehicles and containers, ripening units, and cold stores, and includes energy-saving systems, alternate technologies and the modernization of existing facilities.

Strategically, financial assistance is also provided by exempting the Goods and Services Tax on cold chain services when used for agricultural produce, including milk. Furthermore, the cold chain sector is notified under banking rules for priority lending to ease credit availability through commercial banks. Such schemes aim to provide connectivity in the cold chain and provide financial assistance (35 to 50 per cent) for all cold chain components, such as the packhouse, reefer transport and ripening chamber.

Other interventions include setting up the National Centre for Cold chain Development (a nodal advisory body to guide policy) in 2012 and the release of the India Cooling Action Plan in 2019. The government also released the minimum system standards in 2015 to guide new cold chain infrastructure development, which are applied across ministries and sectors and have helped converge associated support programmes. India also undertook a comprehensive baseline survey that collated granular technical data and geotagged all the cold store installations in the country, and conducted a comprehensive analysis of the status and gaps in the cold chain. A reverse fork-to-farm approach was adopted to assess the cold chain infrastructure needed to meet existing consumption patterns and projected the information out a decade. These studies laid the premise for rationalizing the support programmes of the government and for the addition of the cold chain agenda in the India Cooling Action Plan.

The government of India recognizes that the country's cold chain is incomplete and encourages a collaborative pathway that dovetails national efforts with those of international and multinational agencies, industry, academia and other involved stakeholders.

Source: P. Kohli, personal communication, August 2021 to promote private sector participation to invest more in warehouse, silo and cold storage facilities to help strengthen the distribution of fisheries and agricultural products (Box 23). In East Africa, ARCH Cold chain Solutions is investing in the development, construction and operation of new cooling warehouses as well as a fleet to reduce the high rates of spoilage of perishable goods (around 90 per cent for agriculture/food and 10 per cent for pharmaceuticals) due to lack of refrigeration (Box 24).

Inadequate legislation and standards

In many countries, legislations and standards are often narrowly defined to a specific sector or are not well administered. This tends to confuse and disconnect the application of these measures in services such as the cold chain, where the seamless integration of activities from different sectors is critical. It is important that regulations and standards encourage the convergence of cross-sectoral technologies and practices in the food cold chain, which materially dovetails multi-sectoral operations.

Similarly, legislation and standards are not well aligned to the technological progress. Minimum energy performance standards (MEPS) and labelling programmes are powerful tools for governments to raise consumer awareness about the impact of equipment and to drive inefficient and polluting equipment out of markets. However, many governments have yet to adopt MEPS and other measures effective in promoting sustainable cold chain technologies. Where standards do exist, they are typically not ambitious enough to bring the best-performing available technologies to market at scale.

Labels and standards should recognize what is already possible and encourage equipment manufacturers to continually produce equipment that is more energy efficient and has lower GWP. Japan's Top Runner Programme is a best-practice example, designed to stimulate continuous improvement by setting energy efficiency targets for appliances based on the most efficient model available on the market (Future Policy 2014). Globally, the United for Efficiency Model Regulation Guidelines provide voluntary guidance for governments in developing and emerging economies that are considering a regulatory or legislative framework (Box 25).

Box 23. Thailand's Warehouse, Silo and Cold Storage Act

Thailand's Warehouse, Silo and Cold Storage Act was drafted in 2017 with the aim of encouraging the private sector to invest more in warehouse, silo and cold storage facilities to help strengthen the distribution of fisheries and agricultural products. It reduces both the approval process and the time taken to obtain a licence, in order to give entrepreneurs easier access to such facilities. The Director General of Internal Trade is now the approving authority, rather than the Commerce Minister, which previously approved every investment. The Act is also being used to monitor the operations of cold storage businesses, with provisions for penalizing defaulters and restricting illegal and unorganized facilities.

Source: UNEP

Box 24. The ARCH Cold chain Solutions East Africa Fund

The ARCH Cold chain Solutions East Africa Fund aims to install a total cold storage warehouse capacity of around 100,000 pallets by building and operating 8-10 facilities in Kenya, Ethiopia, Uganda, Rwanda, Tanzania and potentially elsewhere. The facilities will be based on green building standards and will adopt LEED (Leadership in Energy and Environmental Design) certification. The operating units will integrate flexible racking systems and employ natural refrigerant-based technologies. The investment components will comprise site wastewater treatment plants, integrated power generation with rooftop solar photovoltaic systems, docking bays and supporting facilities. The Fund's target size is $100 million, with total project costs estimated at $210 million.

Source: A. Shakir, Global Gess, personal communication, August 2021

Box 25. The United for Efficiency Model Regulation Guidelines

Typical cooling appliances and equipment (vapour compression-based systems) require electricity and a refrigerant gas to operate. When the electricity comes from fossil fuel power plants – the case for nearly three-quarters of the electricity in non-OECD countries – greenhouse gases and air pollution are emitted. Many refrigerants have a global warming potential that is well over 1,000 times as potent as an equivalent molecule of CO_2. Technologies are widely available to improve energy efficiency and to use refrigerants with lower climate impacts, and MEPS and energy labels are among the fastest and most effective approaches to improve efficiency and reduce emissions. Although numerous countries have pursued such policy interventions, many of these are out of date and unenforced. Inadequate measures leave markets vulnerable to being dumping grounds for products that cannot be sold elsewhere.

The United for Efficiency Model Regulation Guidelines contain essential elements, including product scope, definitions, test methods, minimum efficiency levels and a set of minimum performance requirements, along with market surveillance measures that ensure that consumers can purchase quality efficient products with confidence. For example, the projected stock of equipment of the types covered by the Commercial Refrigeration Equipment Guidelines, released in November 2021, is expected to rise significantly in developing and emerging markets. The key is expanding access to cooling while mitigating impacts on energy supplies, the environment and the planet. Electricity consumption varies widely by equipment type, size, age and maintenance practices.

Inefficient commercial refrigeration equipment meant to be addressed by these Guidelines can consume more than 10,000 kWh of electricity per year, whereas some of the best equipment can consume less than one-fifth as much for the same display area or storage volume. Such savings have profound impacts on the cost of owning and operating these devices. If the Guidelines' minimum efficiency level ambition scenario is pursued across all developing and emerging economies, the annual savings realized by 2033 will total 42 terawatt-hours of electricity, equivalent to the output of 65 power plants. In addition, the electricity saved will result in a reduction of 40 million tons of CO_2 emissions, and $3.9 billion in electricity bill savings.

Initial commercial refrigeration projects in Brazil and Chile have been announced that will use the Guidelines to inform new MEPS and labels, and many others are in the pipeline. Similar work is under way at the regional level towards policy harmonization with 10 countries in Southeast Asia and 21 countries in Eastern and Southern Africa. Both regulatory and voluntary incentive-type interventions are under way leveraging these tools.

Source: UNEP United for Efficiency

Apart from labels and standards, wider legislation that could encourage the transition to sustainable food cold chains is often weak and/or poorly implemented. The UK government only recently announced plans to remove subsidies for red diesel used in transport refrigeration units in 2022 to encourage cleaner transport (Government of the United Kingdom 2021). However, this also requires financial support to assist businesses in transition. According to the Cold Chain Federation, this change will add costs totalling 100 million British pounds to the supply chain (Global Cold Chain News 2021). As of October 2021, the United Kingdom's cold chain sector had not yet received any direct support from the government.

Inability of small-scale farmers to afford sustainable cooling technologies under existing finance and business models

Cooling technologies (sustainable or not) tend to have high initial capital costs, limiting the uptake of these technologies by small-scale farmers. To deliver sustainable cold chains affordably in local economies, particularly in developing countries, new finance and business models directed to small and marginal farmers are needed to enable equitable distribution of risks and costs to overcome issues around affordability and viability as well as the value created from investments in cold chain equipment and infrastructure.

Microfinance institutions could play a key role in enabling smallholder farmers or local entrepreneurs to purchase new sustainable equipment technologies and in reducing long payback periods by providing mechanisms that tie repayment amounts to income generated. Financial incentives, such as equipment subsidies, that reduce the upfront cost of sustainable equipment can also be effective to increase uptake. In addition, financial barriers and investment risk could be addressed through servitization models that eliminate the need for farmers to incur capital costs on asset ownership as well as maintenance costs, such as Pay-As-You-Go (PAYG) and Cooling-as-a-Service (CaaS) (Box 26), as well as through equipment rental/leasing models and bulk procurement programmes (Box 27).

Box 26. The Basel Agency for Sustainable Energy (BASE): Cooling-as-a-Service

Cooling as a Service (CaaS) is an innovative business model that enables end users to access clean and efficient cooling solutions without the need for upfront investment. This servitization model addresses the key market barriers that hinder the adoption of sustainable cooling (higher upfront cost, technology risks and competing investment priorities) by allowing customers to pay for the service consumed on a known-fee-per-unit basis. In the agricultural sector, especially in remote areas within emerging economies, this supports smallholder farmers to store their produce at an affordable cost, sell it at the appropriate time at an appropriate price, and thus reduce the amount of food spoilage. It can also increase farmer revenues, in addition to reducing the stress on farming the land and enabling more effective resource use. Meanwhile, ownership of the system remains with the technology provider, who is responsible for system service and maintenance along with all operation costs. Hence, providers are incentivized to improve their energy efficiency to increase their profit margins.

Through its CaaS initiative (www.caas-initiative.org), the Basel Agency for Sustainable Energy (BASE), with support from the Clean Cooling Collaborative (CCC, formally known as the Kigali Cooling Efficiency Program K-CEP) and endorsement from the Global Innovation Lab for Climate Finance, has accelerated the adoption of the CaaS business model globally in a variety of sectors and industries, from industrial refrigeration and commercial air conditioning to agricultural and medical cold chains. The aim is to reduce energy consumption and greenhouse gas emissions from cooling use, while supporting sustainable development and access to cooling.

To complement the CaaS Initiative, BASE is leading – together with its partners from the Swiss Federal Laboratories for Materials Science and Technology (Empa) – the project Your Virtual Cold Chain Assistant (www.yourvcca.org), through which the partners are developing an open-access, data- and science-based mobile app for cold-room users and operators. The app digitizes walk-in storage processes, allowing farmers to track the remaining real-time shelf life of their crops in storage, while simultaneously providing valuable market intelligence as well as best practices. This allows farmers more time to sell their crops, increasing their incomes and reducing food spoilage.

The app is being designed and field tested by BASE and its local partners offering cold storage under the CaaS model in India (with the support of the data.org global innovation challenge funded by the Rockefeller foundation and Mastercard Center for Inclusive Growth) and in Nigeria (with the support of the German Federal Ministry for Economic Cooperation and Development (BMZ) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.).

Source: R. Evangelista and D. Karamitsos, BASE – Basel Agency for Sustainable Energy, personal communication, August 2021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Box 27. Ecozen Solutions: Flexible models

Ecozen Solutions is an Indian provider with two cold chain products. The first, Ecofrost, is a solar-powered cold room with modular, scalable and portable storage capacity starting at 2 tons. The standard capacity unit of 5 tons is mounted with solar panels (5 kW-peak) to actively power the inverter technology-based refrigeration system, as well as to charge a 30-hour power back-up system. The back-up uses 62 thermal plates for energy storage, replacing traditional electrical batteries to reduce operating costs. The entire system can be moved from one place to another as required to support needs at both harvesting or distribution points in the supply chain. The system is designed for a temperature range of 4°C and equipped with the Internet of Things and artificial intelligence to enable predictive maintenance. The company also offers a grid hybrid system.

Ecofrost costs around 1.2 million to 1.5 million Indian rupees ($17,000 to $21,000) and is eligible for a subsidy under India's cold chain supporting schemes. The government provides a capital subsidy of 35 to 40 per cent to install solar-powered cold stores. The main customers of the company are farmers or farmer groups, supply chain companies, modern retail, non-governmental organizations or other members of civil society. The Ecofrost systems are deployed at the farm gate as well as at receiving markets.

To suit different needs, Ecofrost is marketed under three business models: 1) upfront purchase (direct sale), 2) lease-rental (asset hiring) and 3) a community model (pay per use for service). In all cases, the company installs the system, and users can choose to either own it outright, lease it for their own operations, or pay user fees for the time and amount stored, with the company managing the operations. In addition to providing after-sales service for the product, the company supports farmers with market-led advice and in improving the quality of their crops, reducing losses and optimizing their returns.

The company's other product is Eco-connect, a web- and app-based service that connects farmers with buyers and facilitates transactions. Eco-connect fetches prices of perishable commodities from different markets to aid producers in deciding on suitable buyers. Conversely, buyers can access the availability of produce with assurance of quality and transact with farmers. To facilitate the transaction, Ecozen also undertakes the cold chain movement of the perishable produce.

Through both products, Ecofrost and Eco-connect, Ecozen provides solution-based services to farmers and buyers, especially where large-volume cold chain capacities are not feasible. The products allow the company to create solutions and models that can service different customer profiles with business models to suit customers' requirements and buying capacity.

Source: S. Deshmukh and R. Dolare, Ecozen Solutions Pvt Ltd, personal communication, August 2021

Lack of awareness among food consumers, producers, cold chain operators and service providers

Consumers are often not aware of the emissions impact of the system that delivers them food. Similarly, while food cold chain operators may generally be alert to the energy consumption, maintenance and operating costs of the cooling equipment they own, they are not fully informed of the larger emissions impact. Sometimes there is a lack of discerning information about the availability and life cycle benefits of more efficient equipment. To raise awareness of the benefits of more sustainable cooling technologies, labels and MEPS as well as demonstration projects to show impact are critical.

Similarly, cold chain operators frequently lack the skillsets needed to manage and use sophisticated cold chain equipment. Given the relatively lower literacy rate among women globally, and the high share of women in the agriculture sector labour force in developing countries (SEforALL 2021), the situation for women farmers is even more challenging, in terms of their awareness of post-harvesting cold chain solutions and their efficient operation. This is in addition to challenges related to access to training and education, which might be greater for women.

Farmers are typically focused on production aspects and are not knowledgeable about the varied functions and potential benefits of different elements of the food cold chain. This leads to inadequate preparation of crops before they enter the cold chain as produce for the market. For example, pre-harvest irrigation can affect the saleable life of harvested produce, and initial mishandling can result in bruising of the commodity that surfaces after precooling. While precooling is an essential step for maintaining an optimal post-harvest life (Box 2), such facilities are non-existent in many developing countries. The focus should shift from building large cold storage units to integrated consideration of the multiple elements with different functions and requirements (e.g., precooling facilities) that make up the cold chain.

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Lack of clarity on what to invest in

Many investors and donors are still not fully aware of the impact of cold chain interventions that they are supporting. This can result in financial support going to sub-standard interventions, leading to inefficient allocation of resources with loss of greenhouse gas mitigation opportunities and potentially higher financial costs in the long run, with equipment needing to be replaced early or retrofitted to comply with new regulations and standards.

Similarly, the cold chain sector needs more clarity on governments' decarbonization strategies to trial and adopt new technologies. For example, the United Kingdom's strategy on lower-emitting fuels (such as hydrogen and nitrogen) for transport refrigeration units is little known (Cold Chain Federation 2021b). According to a survey by the Cold Chain Federation, "lack of clarity on what to invest in" is identified as the top inhibitor to achieving net zero emissions in cold chain fleets, receiving 53 per cent of responses, followed by "lack of technology" with 24 per cent (Fig. 8) (Southall 2021).

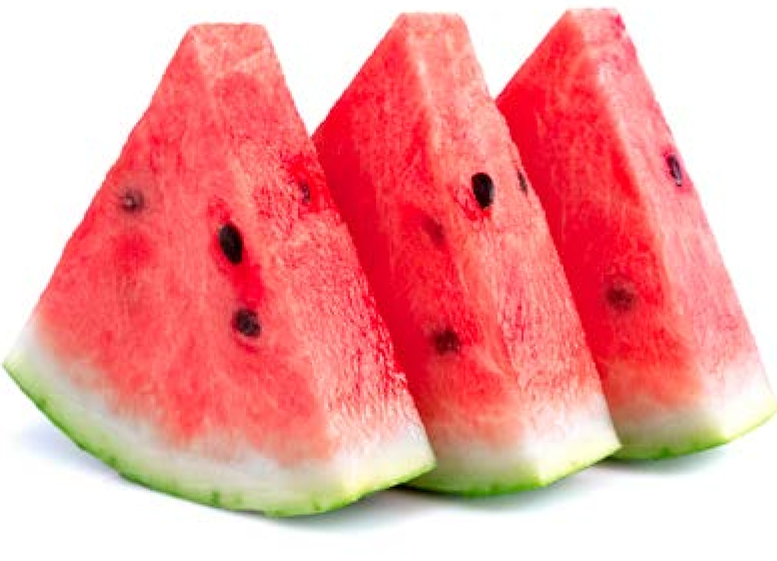
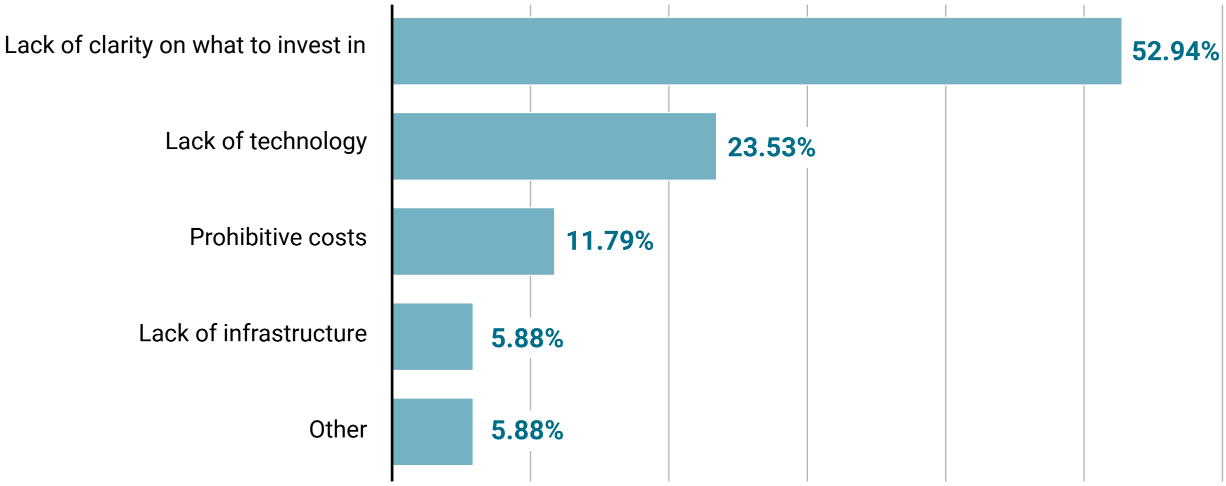


Figure 8. Cold Chain Federation survey on barriers to decarbonizing cold chain fleets



Source: Adapted from Southall 2021

Lack of skilled technicians to deploy, operate and maintain new technologies and to decommission existing systems and end-of-life technologies

The necessary resources, tools and skills to deploy, operate and maintain new technologies as well as safely decommission old systems containing harmful refrigerants and materials are often lacking in developing countries. The need for these processes is increasing and creates a substantial skills requirement around safe handling of refrigerants and safe disposal. The need for dynamic and continuous training has also become critical in developed countries as they transition to alternative refrigerants and novel technologies, given the rapid pace of advancements and the digitalization of the cooling sector.

For example, as early as 2012 – as the European Commission worked on an HFC phase-down in the context of revising the European Union's 2006 F-Gas Regulation – the Air Conditioning and Refrigeration European Association (AREA) warned of the risk of shortage of contractors trained in the use of low-GWP refrigerants, against the estimated demand. A decade later, the situation has actually worsened: training rates have remained largely stable, whereas demand for low-GWP alternatives has increased substantially. The issue is widely acknowledged and is considered to be a major obstacle to stronger market uptake of alternative refrigerant solutions. As these alternative solutions become available for a growing number of applications, additional certified contractors are needed to safely work on them (Box 28).

While most established equipment providers set up service centres to warrant the equipment upkeep in the initial year and offer training to their customers, this is not always sufficient and comprehensive. To this end, there is a need to quickly assess and strengthen the skills and training required to deliver current sustainable technologies in the market, as well as to scan the horizon by engaging with industry and technology developers to understand the potential future skill requirements. During maintenance, refrigerant gases need to be properly recovered, and there is a potential for their further recycling and reclamation to avoid the production of new virgin gases. However, this has had a limited application, especially in developing countries, due to lack of incentive and needed scale to run self-sufficient business models. This can be an important element to consider in integrated policy approaches to delivering cold chains.

Box 28. Training technicians in the servicing sector on alternative refrigerants: The experience in the European Union

The Air Conditioning and Refrigeration European Association (AREA), founded in 1988, represents roughly 13,000 companies and 110,000 technicians in the refrigeration, air conditioning and heat pump servicing sector, mainly in Europe*. It is involved in numerous cold chain projects in both developed and developing countries, targeting technological challenges and options for transitioning to zero-ODP and lower-GWP refrigerants and promoting energy efficiency as well as policy options.

AREA highlights the many challenges facing the servicing sector, including those related to infrastructure, electricity, systems maintenance, appropriate equipment and competence. Over the past decade, AREA has conducted intensive work at the EU level on training and certification, which has resulted, among others, in the certification of 500,000 technicians, the improvement of working systems, and the increased recycling, recovery and reclaim of refrigerants.

Similar work needs to be carried out for new alternatives and natural refrigerants, in particular to prevent leakages and enhance safety. These types of refrigerants can only be used in systems with specific, fit-to-purpose designs, and thus must be implemented in new systems. Natural and low-GWP synthetic refrigerants play a key role in the servicing sector. AREA has already studied the use of appropriate technologies in certain applications (such as supermarkets and storage), but similar research is needed in other fields such as transport refrigeration.

In a recent survey, AREA found that only between 3.5 per cent and 7 per cent of the personnel certified to handle fluorinated gases (F-gases) in the European Union are trained on low-GWP alternatives, depending on the refrigerant (Fig. 9). More than six years after the entry into force of the EU's revised F-Gas Regulation, and as the phase-down of HFCs in the region accelerates, such a low figure provides clear support for AREA's call for mandatory certification on refrigerant alternatives.

A simple solution would be to extend the EU's existing mandatory F-gas certification scheme to low-GWP alternative refrigerants. This would ensure proof of certified training for operators performing installation, repair, maintenance, gas recovery and leak detection in plants and equipment containing these substances. Such a move would provide a sufficient number of contractors with the necessary level of competence to ensure safe, efficient and reliable handling of equipment operating with low-GWP refrigerants. To this end, AREA has prepared concrete proposals on training, including minimum requirements, to increase the attractiveness of the servicing sector in providing quality jobs for young people, and towards achieving greater gender balance in the sector.

In total, around 345,000 personnel in the refrigeration, air conditioning and heat pump sector are F-gas certified in the 18 EU countries covered by AREA membership. The figure increases to 397,000 if the United Kingdom is included, and to more than 433,000 if Norway and Turkey are included. Around 85 per cent of the certifications are in Category I (the most comprehensive category, covering leakage checking, refrigerant recovery, installation, maintenance and servicing). In addition, 116,500 companies are F-gas certified in the 18 EU countries covered by AREA membership (rising to 125,000 companies if the United Kingdom is included).

– Marco Buoni, President, Air Conditioning and Refrigeration European Association (AREA)

* AREA represents contractors from 25 National Associations in 18 EU countries as well as United Kingdom, Norway and Turkey Source: AREA 2021

Source: UNIDO

Figure 9. Proportion of F-gas certified personnel trained on alternatives

Ammonia	CO_2	HC (small)	HC (large)	HFOs
7%	6.9%	6.2%	5.3%	3.5%

HC = Hydrocarbon refrigerants
HFOs = Hydrofluro-Olefins refrigerants
Source: AREA 2021

Dumping of sub-standard equipment to developing countries

As developed countries impose increasingly stringent equipment standards, countries in the developing world face the risk of becoming dumping grounds for unsustainable equipment with low energy efficiencies and containing refrigerants with high ozone-depleting and/or global warming potentials. This can include both second-hand and new products that cannot be sold in the country of manufacture due to failure to meet minimum regulations and standards. Developing countries, in the absence of adequate equipment regulations and standards as well as robust monitoring and enforcement to prevent illegal imports, can be locked into obsolete and sub-standard technologies for the next 15-20 years. For example, 75 per cent of the refrigerators imported into Ghana from 2004 to 2014 were second-hand (Green Cooling Initiative 2020).

Illegal trade of counterfeit refrigerants and non-quota HFCs

Counterfeit refrigerants are a long-existing problem that emerged with the Montreal Protocol-led phase-out of ozone-depleting substances in 1987. It has since grown in the wake of restrictions posed by efforts such as the Kigali Amendment and the European Union's F-gas Regulation. As supplies diminish and prices rise under European HFC quotas, illegal trade of non-quota HFCs has become an issue that needs to be addressed. In 2020, the Environmental Investigation Agency conducted an undercover operation to reveal the illegal trade methods and companies and individuals involved in such activities. Investigators were offered 17.5 tons of suspected non-quota HFCs in total, with a global warming impact of 31,255 tons of CO_2-equivalent (EIA 2021b).

As the world continues to phase down HFCs under the Kigali Amendment, there is an urgent need to strengthen the current monitoring and enforcement system and to improve enforcement capacity globally. These efforts can be supported by more ambitious regulations on cooling equipment regarding refrigerants to reduce the demand for HFCs (EIA 2021b).

Lack of or unreliable energy access in developing countries

In 2020, 789 million people did not have access to electricity in their homes or communities, and rural populations make up around 85 per cent of this deficit (International Energy Agency *et al.* 2020). This limits the use of cooling technologies. Because of the lack of electricity access, combined with high electricity tariffs, many rural cooling services typically rely on expensive fossil fuels that have significant climate and environmental impacts. Unreliable energy supply also limits the viability of some sustainable cooling technologies in developing countries: for example, CO_2 refrigerant systems are much more susceptible to loss of full charge during power outages (Merrett 2020). To address these challenges, some companies are developing alternatives that use renewable-powered cold chain technologies, such as ColdHubs' solar-powered cold rooms in Nigeria (Box 29), Adili Solar Hubs in Kenya (Box 30) and electricity-free evaporative cooling (Box 31).

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Box 29. ColdHubs: Solar-powered walk-in cold rooms

ColdHubs Ltd. is a social enterprise that designs, builds, commissions and operates solar-powered walk-in cold rooms in farm clusters, produce aggregation centres and outdoor food markets. The Hubs are used by smallholder farmers, retailers and wholesalers to store and preserve fresh fruits, vegetables and other perishable foods. Each ColdHub includes a cold room that can fit around 3 tons of perishable food arranged in 150 units of 20 kilogram plastic crates stacked on the floor. In addition to deploying technology, ColdHubs educates the various food supply chain actors by organizing and imparting to them comprehensive skills and knowledge on post-harvest management of perishable food using local language educational comics.

ColdHubs currently serves some 5,250 farmers, retailers and wholesalers using 54 installed cold rooms in 38 farms, aggregation centres and markets in the southern and northern regions of Nigeria. Users pay 100 Nigerian naira ($0.26) to store one 20 kilogram returnable plastic crate per day inside the cold room – a unique pay-as-you-store Cooling-as-a-Service (CaaS) concept.

In 2020, the 54 operational ColdHubs saved 42,024 tons of food from spoilage. The Hubs increased the household incomes of participating small farmers, retailers and wholesalers by 50 per cent, adding $60 to the previous $60 earned, for a total monthly income of $120, simply by eliminating the previous food loss of 50 per cent. The Hubs also created 66 new jobs for women, by recruiting and training them to work as Hub Operators and Market Managers in markets and farm clusters.

Source: N. Ikegwuonu, ColdHubs, personal communication, August 2021


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Box 30. Enhanced cold chain in Kenya: Delivering access to energy and water and improved income for fishing communities

Adili Solar Hubs in Kenya has been helping marginalized fishing communities that lack access to clean water, clean energy, finance and technology to take a whole-system approach to establishing a cold chain for fish, from source to market. Longech, in Tukana County, Kenya, has installed a cold chain hub* with the support of Adili Solar Hubs that includes a water treatment unit, an ice flake machine for chilling fish prior to processing and during transport, cold room/storage of fish prior to transport to the urban market, as well as a monitoring, data acquisition and control system for the hub processes. The system is powered by an off-grid solar mini-grid clean energy system.

As a result, the fishing community can increase its income by selling the fish fresh rather than dried (which results in losing over half the value of the fish and incurs the extra cost of salting and drying it for preservation). The community also benefits by gaining access to clean drinking water from the facility, while urban markets benefit by acquiring hygienically processed fresh fish from the hub. Having a processing facility at the landing site creates employment opportunities for local people as well as a ready market, preventing spoilage.

* Note that while the model is exciting, Adili Solar Hubs currently uses R-404A in its cold room, which has a high GWP of 3,920.

Source: FAO

Box 31. Evaptainer: Decoupling refrigeration from electricity

Evaptainer is a low-cost, electricity-free mobile refrigeration unit that uses evaporative cooling to keep perishable produce cool. Evaptainers make use of a patented PhaseTek™ membrane technology that enables and enhances the evaporative cooling. The technology becomes activated when the internal reservoir is filled with water. The walls of the device then begin to draw out heat from the interior of the device through evaporative cooling. Evaporative cooling systems are especially effective in regions with hot, dry climates, are comparatively inexpensive to run, and are a good alternative to traditional refrigerant-based active cooling systems.

Source: UNEP

Poor road infrastructure, which constrains cold chain connectivity

In many developing countries, poor roads prevent connectivity between agricultural production areas and the market. Inadequate transport infrastructure leads to increased transport times, increased risk of physical damage to produce, shifting loads and increased risk of damage to cooling equipment (GIZ 2016). As part of their infrastructure development, developing countries should also plan for the charging infrastructure to support electrified transport. Even in the developed world, there is insufficient infrastructure to support electric mobility and only limited trials of key innovations for logistics such as wireless charging .

Lack of demonstration projects in both the developed and developing world

Demonstration projects can show feasibility, financial viability and reliability. They can demonstrate the impact of new and emerging technologies as well as finance and business models through live market testing and validation. However, such projects are largely lacking in many countries.[18]

4.3 ADDITIONAL CONSIDERATIONS

In addition to understanding the drivers and barriers for sustainable food cold chains, several additional considerations need to be taken into account. These are discussed below.

Taking a localized perspective

It is critical to take a localized perspective to understanding current and future food cold chain needs and requirements. There is no one-size-fits-all solution. Differing technology, market and regulatory ecosystems will dictate the cold chain development pathways that countries must follow. For example, the diets and buying habits of populations have a direct impact on the type and capacity of cold chains that a region will develop. Similarly, the barriers to enabling sustainable cold chain development differ among regions.

In the context of technologies, developed countries have the capacity and resources to improve their food cold chains in response to the urgent need to decarbonize their economies, by upgrading existing systems and deploying environmentally friendly technologies. In contrast, some developing countries may continue to use conventional (lower-cost but higher-climate-impact) cooling technologies in the attempt to improve their food cold chains, finding it more relevant to await further advancement or cost reduction in more sustainable systems and to build up local capacity for installation and maintenance. In doing so, they run the risk of deploying short-lived solutions and finding themselves in a technological lock-in, with serious environmental, social and economic consequences in the long run.

For example, refrigeration equipment installed today may stay in operation for the next 10 or more years, resulting in a lock-in over long periods in some sectors of the food cold chain. The periodic refurbishment of refrigeration and insulation components that is undertaken tends to perpetuate the old technology, unless market availability or compliance with regulations enforces a change. This challenge would persist in the absence of technology and knowledge transfer from the developed world and must be rectified quickly. One study suggests that bringing food cold chains in developing countries to the

18 The first UK trial of wireless charging technology for light commercial vans was launched in Edinburgh (Ford 2021).

same level of equipment and performance as those in developed countries would reduce the overall carbon footprint associated with the global cold chain by more than 47 per cent (including emissions both from current cold chain equipment and related to food losses due to lack of refrigeration) (IIF/IIR 2021).

Incentivizing industry and diverse financing and business models

To accelerate the transition to sustainable food cold chains, there is a need to incentivize industry to scale up sustainable solutions and technologies and services that are better suited and differentiated across countries, in the context of financial, operational and infrastructural challenges.[19] Long-term industry engagement is also needed to help developing countries build the necessary services, skills and capacity to adopt, operate and maintain the new technologies and to better prepare the market for absorbing them, ultimately leapfrogging to advanced sustainable solutions and being able to fully reap the associated economic, social and environmental benefits. To this end, equipment regulations and standards should be aligned to the technological progress to bring sustainable technologies to market.

It is equally important to develop and implement finance and business models, such as servitization, that create and share value and overcome perceived issues around affordability and viability.

Improving the business case

Likewise, the economic, social and environmental benefits of delivering sustainable cold chain solutions should be identified and quantified – realizing that social and environmental benefits often come with additional economic benefits and can improve the business case if properly accounted for – to underpin the investments in sustainable cold chains. For example, undernutrition can greatly exacerbate death rates among children (contributing to more than half of global child mortality, which will in turn reduce the workforce and impact national productivity, with consequences for the economy (UNICEF 2021; Uribe and Ashing 2021). Quantifying the benefits of sustainable cold chains requires benchmarking the impacts of the current food cold chains.

Building skills and capacity

Especially in developing countries, material barriers to the market uptake of sustainable cooling solutions have meant that the cooling industry has been slow to innovate solutions that fit with the local context and scale up rapidly. The opportunity is that developing countries are less encumbered by outdated intermediate technologies than developed countries and should aim to leapfrog to more advanced sustainable solutions when possible. To unlock this opportunity and drive industry engagement, developing countries should start building the skills and capacity required to ensure proper installation and servicing of next-generation, more technically complex, data- and system-connected equipment with lower- or zero-GWP refrigerants, while taking action in the short term to reduce cooling loads, the energy requirements of equipment and the GWP of refrigerants in their markets.

19 As an example, Danfoss is currently developing a bundled "plug and play" solution that is easy to maintain and install. The refrigeration unit generates cold when electricity is available on site (solar panels) or by using the grid, and cold storage with ice covers the hours without electricity. The refrigeration unit generates cold when electricity is available on site (solar panels) or by using the grid, and cold storage with ice covers the hours without electricity.

Expert facilitation and national, south-south, regional and global coordination

Facilitation processes are needed to help stakeholders in developing countries develop appropriate policies, capacity building and business models; attract donor support and private sector assistance; and incubate cold chain development and monitor its implementation. This will require close coordination at a global level with experts to engender the exchange of knowledge, indigenize existing successful efforts to suit complexities in other regions, bring standardization of key concepts and set measurable objectives for sustainable cold chain development.

At a national level, for example, India established the National Centre for Cold-chain Development (NCCD) in February 2012 to facilitate and foster various aspects of sustainable cold chain and to liaise with other international organizations and global experts on matters related to the development of sustainable cold chains.

NCCD has since played a pivotal role in transforming India's strategy on cold chain development to have a more holistic systems approach (see Box 34).

At a regional level, the recently launched Africa Centre of Excellence for Sustainable Cooling and Cold Chain (ACES) works to develop and accelerate the uptake of sustainable cold chain solutions in order to economically empower farmers, increase export revenues, enhance rural job creation, improve the climate-adaptive capacity and resilience of communities, reduce climate and environmental impacts, and foster low-carbon development (Box 32).

At a global level, the Cool Coalition Secretariat is coordinating initiatives and experts to facilitate an exchange and transfer of knowledge on best practice between regions, support the development of standard methodologies and tools, and set collective targets and objectives for sustainable cold chain development. Through its political advocacy, the Cool Coalition elevates these efforts in the international policy agenda (Box 33).

Box 32. The Africa Centre of Excellence for Sustainable Cooling and Cold Chain (ACES)

The Africa Centre of Excellence for Sustainable Cooling and Cold Chain (ACES) is a regional collaboration of governments, academia, industry, communities and non-governmental organizations that accelerates sustainable solutions to market to simultaneously address two urgent and interconnected global development challenges: food loss and access to sustainable cold chains and cooling. ACES was established in 2020 by the governments of the United Kingdom and Rwanda, the Centre for Sustainable Cooling, UNEP United for Efficiency and the University of Rwanda, along with UK academic partners including the University of Birmingham, London South Bank University, Centre for Sustainable Road Freight and Cranfield University.

A key goal of ACES is to deliver industry the right environment, sales channels, customer financing models and support for the development, demonstration and marketing, and installation and maintenance of new technologies. Alongside demonstrating and proving refrigeration and cold chain technology in-market, ACES will help build after-sales capability, develop techno-economic business models and financing mechanisms (including climate finance), shape policy and develop capacity through research, teaching and training programmes. The centre will serve as the hub for a network of Living Labs across Africa that demonstrate and implement solutions; the first of these is in development in Kenya.

Source: UNEP and Professor Toby Peters

Box 33. Cool Coalition: Making a systems approach to cold chain the new norm

The Cool Coalition is a global multi-stakeholder network that connects over 120 partners from government, cities, international organizations, businesses, finance, academia and civil society groups to facilitate knowledge exchange, advocacy and joint action towards a rapid global transition to efficient and climate-friendly cooling and cold chain. Cool Coalition members, including 26 countries, are collaborating on science, policy, finance and technology to meet growing demands for cold chain in a comprehensive manner, raising climate ambition in the context of the Sustainable Development Goals while complementing the goals of the Kigali Amendment to the Montreal Protocol and of the Paris Climate Agreement.

In 2019, the Coalition became one of the official outcomes and "Transformation Initiatives" put forward by the Executive Office of the Secretary-General for the UN Climate Action Summit in New York. In 2021, the Coalition collectively mobilized to ensure that the topic of sustainable cold chains was firmly anchored in the UN Food Systems Summit (UNFSS) and its Pre-Summit narrative and agenda, and launched a Summary Briefing for policymakers building on initial findings of this report's development.

The Cool Coalition's collective action forged a new partnership between the Climate & Clean Air Coalition (CCAC), UNEP, FAO and the Government of Italy to promote action on sustainable cold chains with shared advocacy and knowledge development. Shared advocacy efforts ensured the inclusion of Community Cooling Hubs as a transformative solution at the Summit, and in the organization of a global independent dialogue in September 2021 on Sustainable Cold Chain and the Rome Declaration: Delivering Efficient Ozone and Climate-Friendly Cold Chains to Ensure Nutritious and Healthy Food for All. This meeting demonstrated to the Summit's participants the key role of sustainable cold chains in the implementation of the SDGs, and showed how the Montreal Protocol, its Kigali Amendment and the Rome Declaration can contribute to scaling-up of technological and policy solutions.

Building on these efforts, the Coalition continued efforts to increase awareness and mobilize at the High-Level Dialogue on Energy, the 33rd Meeting of Parties to the Montreal Protocol and the 2021 United Nations Climate Change Conference (COP26).

Source: UNEP Cool Coalition

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4.4 SYSTEM-LEVEL THINKING AND NEEDS-DRIVEN INTEGRATED APPROACHES

Systems approaches to food cold chain today typically focus on individual interventions integrated with concurrent energy service needs, such as supermarket refrigeration systems (for products) that recover the waste heat for use in building space heating. Other small-scale efforts that use system-level thinking include India's Impagro Farming Solutions, which developed a framework with practical steps to be taken before, during and after crops enter the farm-level cold chain (Box 34). Over the long term, however, a more holistic systems approach – whereby policy, technology, capacity and finance promote farm-to-fork connectivity – is necessary to meet the challenge of delivering cooling and cold chains in line with climate and developmental targets, and to tackle the barriers to success in the most impactful and efficient manner.

Box 34. Impagro Farming Solutions: A systems approach

Impagro Farming Solutions, a company that provides supply chain solutions in Indian agriculture, takes a systems approach to understand the hurdles that prevent the mass adoption and use of decentralized cold chain technologies by farmers, cooperatives, producer organizations and agribusinesses. The company developed a framework in which it identifies actions to be taken BEFORE, DURING and AFTER crops enter the farm-level cold chain. The aim is to use the framework to develop sustainable business models to operate first-mile supply chains equipped with sustainable cooling technologies.

BEFORE	DURING	AFTER
Cluster Development – It is important to have a strong backward integration with the aggregation centre to provide a consistent flow of crops to it. One way of achieving this is to integrate a nursery service to produce seedlings for the farmer cluster to ensure consistency in crop variety and specifications. **Management of Real-time Crop Data** – Access to real-time local crop production data is imperative to help plan marketing cycles and optimize throughput at a farm-level aggregation centre equipped with a decentralized cooling solution. The data will also be useful in providing agronomic crop advisory to ensure quality production and to manage harvest cycles. **Value Addition** – To maximize the price realization of harvested crops, it becomes incumbent that the cleaning, sorting and grading of the crops are conducted in accordance with market specifications. Due to the added costs of operating a decentralized cooling solution it is important that these costs are recoverable through an added premium paid by buyers.	**Asset Management** – Proper temperature and humidity management of the cooling unit needs to be ensured to achieve the intended results of extending the shelf life and marketability of crops. With increasing mobile data connectivity in rural areas, it is now possible to integrate Internet of Things devices and cloud computing software to provide real-time remote monitoring of the energy, temperature and humidity parameters of the cooling unit. **Spare Parts & Maintenance** – Most decentralized cooling solutions tend to be deployed in rural areas that are not easily accessible. Any system breakdown and/or maintenance can result in disruption and loss to crops stored in the cooling unit. It is recommended that spare parts for the cooling unit are designed in a "plug and play" manner to ensure quick turnaround time to resolve any breakdown and maintenance issues. **After Sales Support** – It may be difficult for service engineers to reach location sites where decentralized cooling solutions have been deployed to provide timely support. Therefore, it is recommended to have an on-demand remote support system in place to provide user training and guidance to the operators.	**Inventory Management** – In addition to the requirement for cooling to reduce losses in perishable crops, it is important that proper inventory management is followed. Use of digital inventory and order management systems can help streamline operations and ensure that inventory is managed on a first-in first-out basis. **Embedded Logistics** – Maintaining in-house logistics for operators of decentralized cooling units may not always be viable. It is recommended that decentralized cooling units offer embedded logistics through a third-party logistics provider to ensure seamless order delivery to buyers at a lower cost. **Embedded Finance** – Farmers who grow perishable crops prefer to off-load the risk of ownership at the earliest instance and therefore seek the most liquid market. Whether the owner of a decentralized cooling unit is operating a trading or Cooling-as-a-Service model, having an embedded finance facility will help the operator manage cashflows and make timely payment to farmers.

Source: A. S. Khan, Impagro Farming Solutions Pvt. Ltd., personal communication, August 2021


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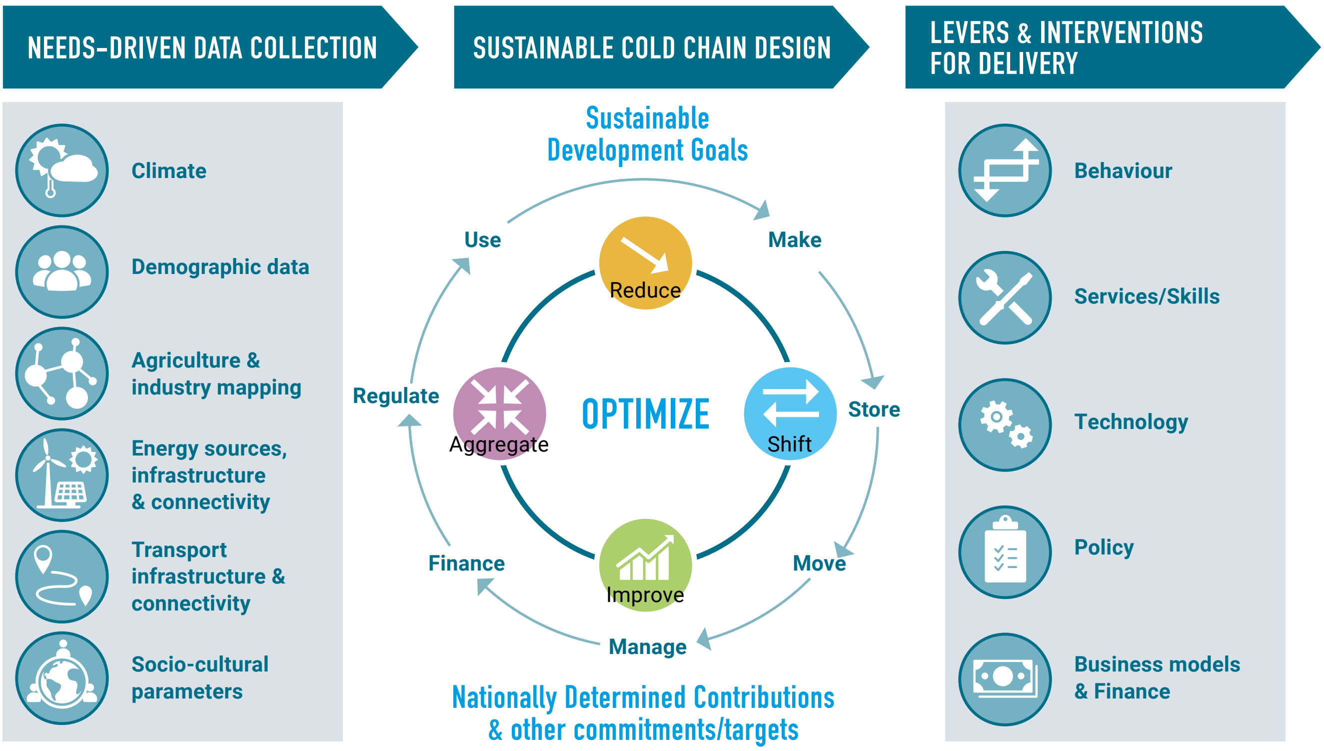
A whole-system, needs-driven approach

Whole-system, sustainable cold chain design starts with assessing the end-to-end cold chain needs along with climatic, demographic, socio-economic statistics, infrastructure, and industry mapping, as well as an audit of existing and emerging technologies, policies, goals, targets, commitments and initiatives. It requires new thinking in key areas on how to use, make, store, move, manage, finance and regulate cold to meet current and future demand through the food cold chain, and to determine areas of intervention considering available energy and thermal resources, emission targets and other commitments, as well as costs (Fig. 10).

India is one of the first developing countries to have considered a whole-system, needs-driven approach to cold chain largely promoted through the National Centre for Cold-chain Development. The NCCD was established in February 2012 with the approval of the country's Cabinet to serve as an autonomous body to drive and facilitate the cold chain development in India (Box 35).

Figure 10. Systems approach to sustainable cold chain design



Source: Professor Toby Peters and Dr. Leyla Sayin

Box 35. India's National Centre for Cold-chain Development: Promoting a systems approach

In 2008, a task force on cold chain development under the Ministry of Agriculture in India recommended having a dedicated agency to drive and facilitate cold chain development in the country. In February 2012, the National Centre for Cold-chain Development (NCCD) was operationalized as an autonomous public-private partnership. The NCCD's main objectives are to recommend, assess, coordinate, undertake, facilitate and foster multiple aspects related to cold chain development. These include infrastructure standards and protocols; post-harvest management; harmonization of best practices, processes and services; guidelines for potential investors; information systems and technologies; research and human resources development; education and awareness-building; multi-modal transport systems; and appropriate policy frameworks.

The NCCD has since played a pivotal role in transforming India's approach to cold chain development. Previously, the government's strategy focused mainly on scaling up investment in cold storage, but the NCCD strongly advised a more holistic systems approach that also emphasized investments in precooling, reefer transport and retailing. As a consequence, the budgetary allocations for cold storage were revised, and multiple new components – such as promoting operational excellence, energy efficiency, alternate technologies and modernization – were incorporated. The government subsidy was designed into an incentive mechanism rather than as a funding grant.

The NCCD guided India's first baseline survey of cold storage starting in 2013 and undertook the country's first-ever holistic assessment of cold chain infrastructure in 2015. The assessment revealed that India already had a very high share of cold storage facilities – around 90 per cent of the required capacity – but that this was not met with associated supply chain capacities. For example, there was a 99 per cent shortfall in modern packhouses and an 85 per cent shortfall in reefer transport. This indicated that rural production capacities were not suitably linked to the market by cold chain and that cold stores were unable to service the domestic production. Thus, the production of perishable food was not reaching its full potential. By closing these gaps, India could increase its annual handling capacity to around 180 million tons across various products.

These assessments complemented the shift in India – initiated by the NCCD – from blind investments in cold storage capacity to end-to-end cold chain that would enable seamless connectivity from source to destination. A digital platform was developed showing the location and capacity of nearly 7,000 cold stores totalling 32 million tons of capacity. For a three-year period, starting in 2014, the NCCD also ran a toll-free call centre to capture on-road challenges faced by domestic reefer truck operators, in order to assess the necessary policy support. In tandem, the NCCD formulated minimum system standards to guide future cold chain infrastructure development and standardized the process for government agencies to utilize the subsidy for cold chain infrastructure in India.

The NCCD also recommended key inclusions in tax laws that would incentivize the use of cold chain capacity, such as exempting various cold chain services undertaken for agricultural produce from the Goods and Services Tax. It also commenced industry partnerships to promote awareness of government schemes (especially in smaller towns) and implemented training programmes for cold chain users. In 2016, the government exempted taxes on services provided by the NCCD to disseminate cold chain knowledge. Also that year, the NCCD completed a pilot study on the kinnow cold chain to establish the positive impact of the cold chain in mitigating greenhouse gas emissions, reducing food loss and improving farmer

Box 35. India's National Centre for Cold-chain Development: Promoting a systems approach (continued)

incomes (see Box 3). To drive home a holistic outlook, the NCCD provided capacity-building sessions on cold chain to government officials. The NCCD was quickly seen as the nodal body on cold chain for the government across sectors and by the private sector in India.

Headed by an industry expert, and functioning without any cost to the government of India, the NCCD is unique in exemplifying a public-private knowledge partnership, with its staff sourced entirely from the private sector. The body's stakeholder members include cold chain operators, logistics service providers, cargo handlers, equipment manufacturers, packaging providers, farmer groups, infrastructure developers, solar and other alternate technology providers, educational and research institutes, state government departments, industry chambers and individuals. The NCCD's cross-functional nature was strategically utilized to reinforce the system-wide impact of the cold chain and to shatter decade-long myths. Most importantly, it helped stakeholders adopt a systems approach that can help fulfil the goals for sustainable development of the cold chain sector. As the umbrella body on cold chain, the NCCD has represented India in various global forums and helped the government develop international cooperation in this domain. The example of India's NCCD can be adapted by other countries to suit their local agenda and to encourage a sustainable future for the cold chain.

Source: P. Kohli, personal communication, August 2021

The whole-system approach considers the full range of drivers and feedback loops within a system. It aims to:

- minimize the greenhouse gas emissions from food cold chain equipment by reducing the demand for mechanical cooling through behaviour change (e.g., avoiding unnecessary delays in closing the doors of refrigerated spaces, harvesting in early morning hours when temperature is low) and the use of passive cooling techniques and approaches[20] (e.g., making use of shades, food packaging to preserve freshness, coatings and treatments);[21]
- make use of natural, renewable and waste thermal energy resources (e.g., surface water bodies, underground aquifers, and industrial waste cooling from regasification of liquefied natural gas, as well as waste heat recovery from refrigeration systems to meet hot water and other heating needs);
- make use of energy-efficient technologies that avoid refrigerants with high GWP;
- take a life cycle analysis and circular economy approach to design, manufacturing, deployment, operation and end-of-life decommissioning;
- balance expansion and development of the food cold chain with the associated food loss and waste mitigation and other environmental, social and economic benefits; and
- enable access and bring benefits related to the SDGs to all.

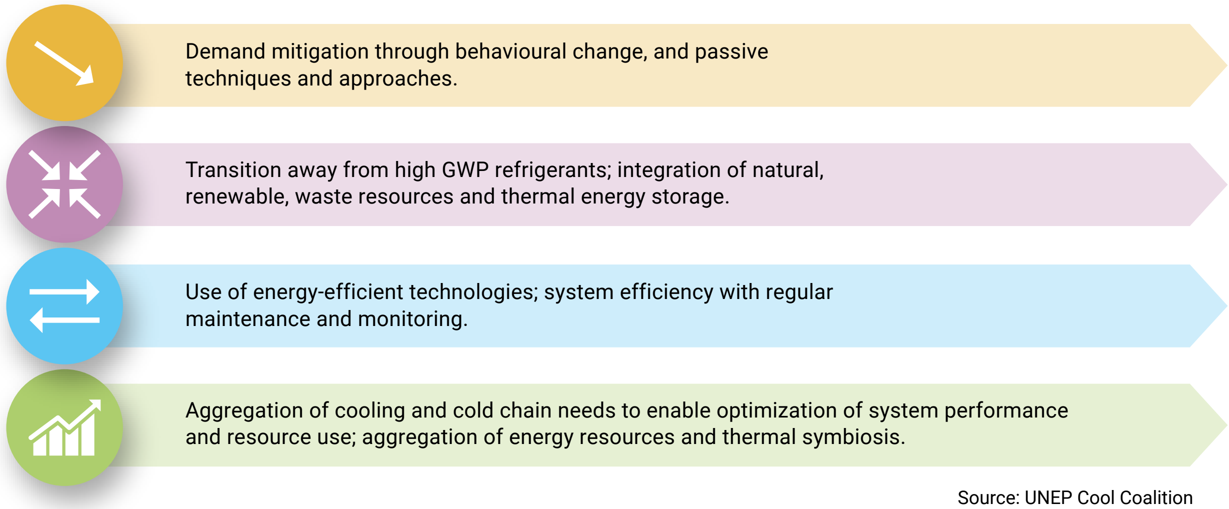
Reduce-shift-improve-aggregate

The optimum mix of fit-for-market sustainable cold chain solutions – across behavioural change, technology, services/skills, policy, business models and finance – can be delivered through a "reduce-shift-improve" approach, adding in the intervention of "aggregate" (Fig. 11). Summarized broadly, this involves reducing cooling demand, shifting away from practices that are unsustainable and that have negative impacts, making improvements through the use of better technologies and efficiencies, and aggregating needs to optimize system performance. Such an approach can support both early wins and the deep systemic changes that are essential to achieve a sustainable cold chain system.

20 Passive cooling systems use stored energy, as opposed to active cooling systems that are connected to an energy source.

21 For example, colouring all refrigerated vehicle bodies white or silver in London can lead to a 1.3 per cent reduction in total annual CO_2 emissions from the refrigerated transport fleet (Cenex 2017).

Figure 11. Reduce-Shift-Improve-Aggregate



Source: UNEP Cool Coalition

Unlocking value-added opportunities

An end-to-end systems approach demands a comprehensive understanding of how all elements of the food cold chain and the wider food system – from food production and preconditioning activities, to packaging, processing, distribution and consumption patterns – are interlinked, and of their collective impacts on society, economy, environment and energy systems. Integrating the needs of these different elements can be facilitated to unlock many value-added opportunities.

For example, through a systems approach, the waste elements that arise in the agri-food chain (such as from processing and packaging) and that are normally ignored can be brought into other gainful uses. Depending on the type of waste generated, the by-products will vary. They can be as basic as vermicompost for organic fertilizer and mulch for fields, or the waste can be processed into organic dyes, fortification for cattle fodder, building materials, biogas for energy, etc. Edible produce that is culled due to physical damage or bruising can be used as feedstock for village-scale or cottage-level micro industry to be processed into pickles, juices, etc. Innovative research is also afoot to use the organic waste created during sorting and trimming at the cold chain packhouse as biodegradable material for packaging, among other uses. Thus, the cold chain need not only serve the purpose of distributing preconditioned produce to consumers; it can also be a source point for converting waste into wealth, supporting and adding to livelihood opportunities in village communities.

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Digital twins

Developing sustainable food cold chains is a multi-dimensional, multi-sectoral challenge. It requires tackling the many interdependencies that exist among economic, environmental, energy, technological, social and political systems, as well as designing and implementing policies to address them. Because the cold chain is a complex system – defined by multiple interdependencies and feedback loops – it is difficult to evaluate in the real world, and large-scale controlled experiments are impossible to implement. This means that real-world interventions are generally a collection of small interventions over long periods of time, which inevitably result in unexpected consequences as the impacts of small changes cascade through the system and meet other cascading small changes.

For these reasons, building "digital twins" – or real-time digital counterparts – to analyse a variety of cold chain scenarios (e.g., technology, logistics and policy interventions) before testing them in the real world would reduce risks and costs. Developing virtual worlds using self-organizing agent-based models can overcome some of the existing challenges and de-risk efforts to improve the performance of the system.

Agent-based modelling assumes a bottom-up approach where the interactions between the component parts of the system are not predetermined. Instead, the agents have the freedom to experiment and make choices that combine to determine the overall characteristics of the system, to which all agents then respond. The model therefore evolves along a pathway determined by the agent's choices instead of a direction predetermined by a scenario. Running thousands of variables in a short space of time, the use of these models can identify interventions that have the greatest possible system-wide benefits and can accelerate the implementation of beneficial changes.

The use of digital twins should be a core feature of sustainable food cold chain design. For example, the Centre for Sustainable Road Freight has developed a standard logistics and energy agent-based model that takes a given logistics demand and allows the agents to make autonomous decisions to improve their performance. The model can self-organize to develop robust and efficient logistics operations for given cold chain scenarios. It allows for robust design of experiments in which the rich model description of the real world can be exercised, and the sensitivity of solutions can be analysed (Centre for Sustainable Road Freight 2021).

Moving forward

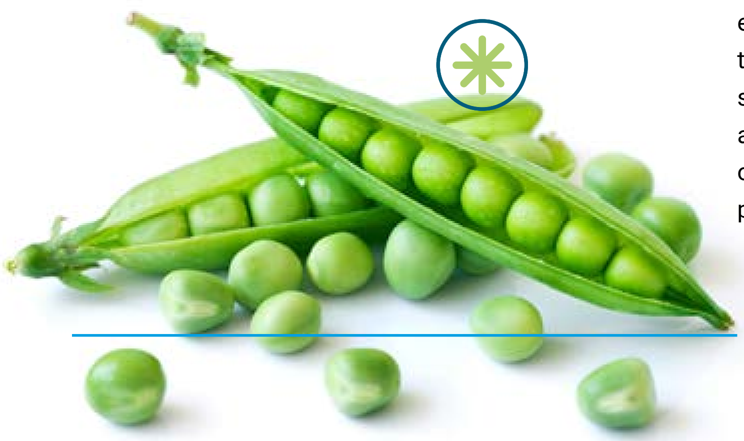
As interest in sustainable food cold chains grows, there is an urgent need to facilitate cooperation among governments of developed and developing countries, the private sector, academia, and international organizations, to incentivize and accelerate innovation and market transformation. This can occur in part through policy actions that: support innovations of technologies and business models via public and private finance; raise awareness of cooling issues among governments, businesses and end-users of the cold chain; and develop the skilled workforce required to facilitate the deployment, operation and maintenance of new technologies (as well as protect against counterfeit refrigerants and components) in developing countries. There is also a need in the developed world to implement dynamic processes for capacity-building of the servicing sector and related skills to meet fast-advancing sustainable cooling technology and fast-changing business requirements.

While there is an increasing recognition that the end-to-end system-level approach is necessary to deliver sustainable food cold chains and to tackle barriers to success both effectively and efficiently, it can be hard to successfully execute in the real world. This type of approach requires cooperation from multiple stakeholders and contains many interdependencies, hence its application is currently limited. Most of the case studies presented in this report are good practices that aim to address individual issues within the food cold chain system and that can deliver quick incremental wins. These cases are included to inspire stakeholders during the short- and medium-term development stages of the food cold chain. Over the long term, however, achieving sustainable food cold chains will require a shift in how we approach cold chain development, away from linear to circular by understanding interconnected and dynamic relationships, and feedback loops within the whole system, as highlighted in the recommendations.

05 RECOMMENDATIONS

Governments, working with industry and other stakeholders, should quantify and benchmark the energy use and greenhouse gas emissions in the existing food cold chain, identify data gaps, develop forecasts and identify opportunities for reductions.

The data on current food cold chain equipment and associated energy use and greenhouse gas emissions are limited. In addition, forecasts are not reliable as they are often based on analysis of historical equipment trends and do not consider the current unmet needs as well as the drivers that will shape cold chain needs and provision over the coming decades. Benchmarking emissions, developing robust needs-based scenario forecasts, and identifying opportunities to reduce energy use and emissions in the cold chain are critical to inform and successfully develop roadmaps and priorities for sustainable food cold chain development in line with climate targets.

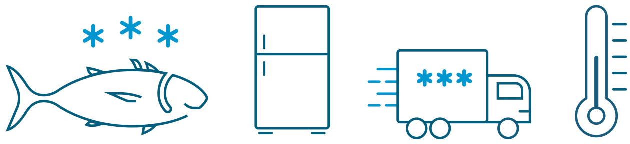


Governments and other cold chain developers should take a holistic systems approach to cold chain provision, recognizing that cooling technologies alone are not sufficient to make an efficient cold chain.

Current "systems approaches" to cold chain focus largely around individual cooling solutions. But while cooling is a necessary condition, it alone is not sufficient to make cold chain services efficient and effective. A holistic systems approach – covering various activities from source to consumption – requires deeper understanding that extends beyond cooling technologies and meets the long-term challenge of delivering the benefits from cold chain services in line with achieving broader climate and other development targets.

A holistic approach demands a review of the system-wide outcomes of the cold supply chain from protecting the quantity, quality, nutritional value and safety of the food and preventing waste. It also requires evaluating the energy loads and the total environmental impact by breaking down each supply chain activity along the cold chain – not just the provision of cooling, but also including components such as packaging, sorting and grading, inventory and asset management, mobility and waste management, all of which require attention from an energy and resource use perspective.

The beneficial impact of the food cold chain cannot be understood completely without adopting a systems approach. A more wholesome understanding will also serve to develop better solutions to tackle systemic barriers in the most effective and efficient manner, to contribute to optimizing production growth through access to demand and market expansion, and to integrate energy management with synergetic uses and other value-adding services. This can be done through:

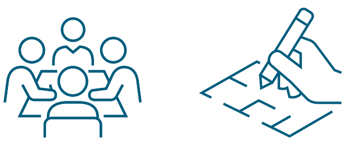


- Understanding and quantifying current cooling demand with existing cold chain capacity and future needs, as well as their associated energy demands and impacts on natural resources and the environment. This should also consider identifying opportunities for aggregation of requirements from other sectors, such as health and thermal comfort, with those of the food cold chain.
- Understanding the current technologies and refrigerants that are in use or easily available.
- Minimizing the need for mechanical cooling through the integration of passive cooling techniques and approaches (such as food coatings, treatments and packaging), as well as promoting behavioural change.
- Making best use of available natural and waste thermal resources.
- Optimizing energy use through the integration of thermal energy storage systems.
- Harnessing and leveraging synergies between systems to create symbiotic yet resilient relationships.
- Understanding and designing for interdependencies across systems and broader infrastructure, and planning for unintended consequences, to ensure holistic sustainability.
- Understanding the policy and financing mechanisms and skills required to deliver the key interventions for the realization of a sustainable cold chain.
- Understanding the bottlenecks in policies, regulations, technologies and domain practices that constrain the synergistic and optimal deployment of cold chain capacities across user sectors.
- Understanding and quantifying how cold chain services directly empower the underrepresented small farmers and producers, including a focus on women farmers, through market expansion and the associated higher economic returns.
- Understanding how cold chain drives gainful productivity from depleting agricultural (land, fresh water, sea) resources, as well as quantifying the value of such gains.
- Conducting a comprehensive cost-benefit analysis (including environmental, social, economic, financial and gender aspects) of introducing new technologies, refrigerants and renewable energy in food cold chains.
- Conducting a sectoral risk-benefit analysis of cold chain's ecological footprint, encompassing energy demand, polluting effects, productivity gains, livelihood sustainability and others.
- Creating a template that recommends measurable outcomes and productivity from cold chain capacities to enable standardized and easy monitoring of all above aspects in future cold chain development.

Governments and other cold chain developers should undertake cold chain needs assessment and develop National Cooling Action Plans to provide the underlying direction for holistic and sustainable cold chain infrastructure creation and to rationalize cold chain programmes across ministries.

Needs assessment is a necessary first step to designing a sustainable and resilient cold chain system efficiently and effectively. This can help in assessing the full spectrum of cooling needs across buildings, cities, agriculture and health, as well as in identifying the policy, technology and finance measures to address those needs. Cold chain assessments should also include disaggregated data on gender, which are limited in the existing research.

Building on the needs assessment, countries can then develop National Cooling Action Plans, using the comprehensive National Cooling Action Plan (NCAP) methodology developed by the Cool Coalition and its partners. This can be used as a key policy tool to coordinate energy efficiency and the phase-down of high-GWP refrigerants in the cooling sector, and to proactively address growing cooling needs while reducing the climate impact of cooling practices, improving access to cooling and addressing several SDGs. NCAPs also help countries create the framework for cross-ministry and multi-stakeholder collaboration required to achieve a holistic and sustainable cold chain.



Governments should implement and enforce ambitious minimum efficiency standards and support robust monitoring and enforcement to prevent illegal imports of equipment and refrigerants.

Through labelling programmes and minimum efficiency performance standards (MEPS), governments can bring sustainable technologies to the market, pushing equipment manufacturers to produce more energy-efficient and lower-GWP equipment as well as fostering innovation, regulating consumer choice and raising consumer awareness about the impact of sustainable technologies. The key is to align these labels and standards to what is currently achievable on the market rather than setting minimum acceptable efficiency levels, and to underpin them with finance and business models to improve accessibility and affordability. This would also be effective in preventing dumping of obsolete equipment by developed countries. Furthermore, robust monitoring and enforcement mechanisms should be put in place to prevent illegal imports of equipment and non-quota/counterfeit refrigerants.

In line with NACPs, governments should develop costed and sequenced five-year plans, missions, policies and dedicated agencies/departments, and provide financial assistance and capacity support for sustainable food cold chain components, with the aim of achieving seamless movement of agricultural products from farm to fork.

This can include creating roadmaps and timetables for achieving a sustainable cooling economy, involving short-term and long-term considerations on refrigerant transitions (the phase-out of HCFCs and the phase-down of HFCs), reducing cooling demand, enhanced energy performance standards (MEPS) and goals for universal access to sustainable cooling.

Governments, working with industry and relevant stakeholders, should build necessary skills and capacity as well as finance and business models in developing countries to support industry engagement and technology deployment at scale.

There is a need to incentivize industry to scale up sustainable solutions and technologies and services that are better suited and differentiated across countries, in the context of financial, operational and infrastructural challenges. To engage industry in closing the technology and development gap, developing countries must build the necessary skills and capacity to adopt, operate and maintain cold chain technologies. This includes dedicated training and educational activities with a gender lens to facilitate access to knowledge for women. With a better-prepared market for absorbing technologies, countries can leapfrog to advanced sustainable solutions and fully reap the associated economic, social and environmental benefits. To this end, it is critical to develop and implement finance and business models, such as servitization, that create and share value equitably and overcome perceived issues around affordability and viability.

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Governments, working with industry and relevant stakeholders, should build digital twins to guide "build-to-suit" projects for local implementation.

Developing a sustainable food cold chain is a multi-dimensional, multi-sectoral challenge. Due to the complexity of cold chains, building digital twins to analyse a variety of scenarios (e.g., technology, logistics and policy interventions) before testing them in the real world would reduce risks and cost. Digital twins can be used to explore through a systems approach how to use, make, store, move, manage, finance and regulate cold to meet current and future demand, and to determine areas of intervention considering available energy and thermal resources, emission targets and other commitments as well as costs.

Industry and civil society stakeholders, backed by governments, should run large-scale system demonstrators to show impact and how interventions can work together to create sustainable and resilient solutions for scaling.

Large-scale system demonstrations are important to provide a ground for accelerated deployment of interventions by eliminating the performance risk and demonstrating impact through live market testing, including the indirect and potential positive and negative consequences. It would also be beneficial to create platforms to disseminate lessons learned and best practices from demonstration projects to support further scaling and replication in other regions.

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Governments and other cold chain developers should collaborate with relevant institutions to quantify and value the broader socio-economic impacts of sustainable cold chains, taking into account poor, disadvantaged and marginalized food producers and their communities, as well as women and youth.

If the expansion is not planned carefully, it will continue to be the poor, disadvantaged, marginalized food producers and their communities, as well as women and girls, who will face the most significant challenges from the lack of food cold chains, and serious equity issues would remain. To this end, understanding, quantifying and valuing the broader economic, social and environmental benefits (in terms of incomes, economic growth, health, gender equity, etc.) of sustainable food cold chains against the targets of the UN Sustainable Development Goals is important to ensure inclusive and equitable growth. Doing this would also increase the scope of return on investment and improve the business case, thereby allowing government interventions and investments to be considered more holistically against criteria that encompass outcome-oriented policy and/or strategic targets, not simply financial goals.

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Governments should institute a multi-disciplinary centre for cold chain development to encourage a collaborative ecosystem of stakeholders, to coordinate on above recommendations and to stay abreast with new developments worldwide. Such national-level centres can also serve to liaise with other international organizations on matters related to development of sustainable cold chains.

Cold chain touches multiple sectoral activities in the supply chain, from the source of produce/products to the final destination. These include the interface of fixed assets such as packhouses, cold stores, ports, retail outlets, etc., as well as mobile components such as trucks, containers, ships, rail and airways. Similarly, it encompasses a variety of allied technologies, financing opportunities, policy and regulatory environments that traditionally come under the purview of sector-specific line ministries or departments of each government. To adopt and coordinate a systems approach across varied sectoral interests and to serve as a one-stop institution on the cold chain system, the establishing of a dedicated centre on cold chain development is recommended.

Such national-level centres will serve as a repository of national data, coordinate with international efforts on sustainable cold chain, and encourage the adoption of a systems approach among all stakeholders, public and private. Setting up of such nodal centres will also indicate the appropriate national emphasis via the Rome Declaration, and provide clarity of intent with agenda that will help in sourcing relevant support from various international bodies, agencies and coalitions related to cold chain. The example of India's NCCD (Box 35) may be reviewed for reference.

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ANNEX: CASE STUDIES

Projects

Developer	Project name	Location	Target applications / cold chain elements
ABACO and Center for Latin American Logistics Innovation (CLI)	Reducing Food Loss and Waste in Supply Chains in Colombia	Colombia	Whole chain

Overview

In Colombia, 54 per cent of the population faces food insecurity (ABACO 2020), while more than 9 million tons of food are wasted (34 per cent of the total), which could feed more than 8 million people (Colombian National Planning Department 2016), almost equivalent to the population in Bogota city. The Colombian Food Bank Association (ABACO) and its 22 food banks recover products that are no longer saleable but are still suitable for human consumption, through collaboration with manufactures and retailers. Some of these products have short expiration dates, damaged packaging or minor labelling errors that do not compromise product safety.

CLI worked with ABACO to develop strategies that reduce food loss and waste by improving the reverse logistical process across the supply chain, from the first to the last mile, meaning from harvest and post-harvest processes up to commercialization operations at the store or food markets. The goal was to raise awareness among the private sector and government that wasting food is not acceptable as a business practice and food insecurity is not an issue of lack of food but a consequence of inefficient logistics operations, especially reverse ones. Some of the initiatives included good practices on product handling and storage, product traceability and route optimization for the food banks.

In 2017, ABACO and the network of food banks rescued 21,807 tons, a 16 per cent increase from 2014. In 2019, despite there being no active project, the food banks rescued 25,089 tons of food, which represented 534 tons of avoided CO_2 emissions. According to ABACO's Annual Report (2019), 3,464 organizations were supported and more than 600,000 people benefited. These figures are not directly related to the initiatives carried out but are an indirect result of years of sensitization and joint work with some of the main donors.

Source: Asociación de Bancos de Alimentos de Colombia, 2020. Informe de Gestión: Bajemos juntos la bandera del hambre en Colombia. [online] Bogotá: ABACO. Available at: https://drive.google.com/file/d/1R0yPmrBbOYiGEiXN0Sok0jJ9I8NAt92R/view. 1 December 2021.

Developer	Project name	Location	Target applications / cold chain elements
Adili Solar Hubs Limited	Adili Cold Hubs	Kenya	Cold storage, data/ monitoring, market connectivity

Overview

Adili Solar Hubs Limited has developed and installed a pilot cold hub in Longech, in Turkana County. The aim is to increase incomes in the fishing community through selling fish fresh versus dried (fishers lose over half the value of the fish and incur an extra cost of salting and drying the fish to preserve it). The community also benefits by gaining access to clean drinking water from the facility. The system has been installed and is being trialled and monitored, with data being acquired to help optimize the efficiency. The hub consists of a water treatment unit (0.5 litres/hour), an ice flake machine (500 kilograms/day; runs on R-404A), a cold room (11 cubic metres; runs on R-404A), 450 litre and 650 litre freezers (run on R-600A) and energy monitoring units on each machine. The system is powered by a 50 kW off-grid solar mini-grid.

Source: K. Gichuche, Adili Solar Hubs Limited, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Alliance for an Energy Efficient Economy	Analysis of Cold Storage infrastructure in West Bengal: Retrofitting opportunities using the energy service company (ESCO) model	India	Cold storage

Overview

This study focuses on West Bengal, a significant horticulture state with substantial scope for improvement in the cold chain infrastructure. With a focus on cold storage facilities, the study conducts field assessment of select cold storage facilities and consultations with diverse stakeholders to understand the state's cold storage scenario and identify the energy performance baseline and state-level energy-saving projections. The study proposes the need for retrofitting-cum-modernization of existing cold storage infrastructure and development of standardized energy efficiency measures. This will ensure better net-capacity utilization, lower operational expenditure, better storage quality (lower losses) and higher price realization. The study also recommends the way forward for large-scale implementation through awareness programmes and improvement in the policy environment governing cold storages. The objectives include:

- Understand the existing cold storage infrastructure in West Bengal
- Identify the potential opportunities to reduce food loss and improve the energy performance baseline of cold storage facilities
- Develop state-level energy-saving projections through the identified opportunities
- Examine the opportunity to scale up implementation through standardization of Energy Efficiency Measures (EEMs) which can be delivered through an ESCO model
- Establish a replicable framework that can be applied to other states.

Source: S. Kumar, Alliance for an Energy Efficient Economy, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
ARCH Cold Chain Solutions Limited	ARCH Cold Chain Solutions East Africa Fund	Kenya, Ethiopia, Uganda, Rwanda, Tanzania and potentially another country	Cold storage

Overview

The Fund aims to install a total warehouse capacity of around 100,000 pallets by building and operating around 8-10 facilities in Kenya, Ethiopia, Uganda, Rwanda, Tanzania and potentially another country.The facilities will be based on green building standards and adopt LEED (Leadership in Energy and Environmental Design) certification. The operating units will integrate flexible racking systems, and the investment components will comprise on-site wastewater treatment plants, integrated power generation with rooftop solar photovoltaic systems, docking bays and supporting facilities. Each cold storage warehouse will employ natural refrigerant-based technologies.

The Fund's target size is $100 million, and the total project costs are estimated to be $210 million.

Source: S. Kumar, Alliance for an Energy Efficient Economy, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Basel Agency for Sustainable Energy (BASE)	Cooling-as-a-Service	Nigeria, Kenya, Tanzania, India	Cold storage, aggregation

Overview

Cooling-as-a-Service (CaaS) is an innovative business model that enables end users to access clean and efficient cooling solutions without the need of an upfront investment. This servitization model addresses the key market barriers that hinder the adoption of sustainable cooling (higher upfront cost, technology risks and investment priorities) by allowing customers to pay for the service consumed on a fixed-fee-per-unit basis. This supports farmers to store their produce at an affordable cost, sell it at the appropriate time at an appropriate price, and hence to reduce the amount of food spoilage, but also to increase the revenues of the farmers, in addition to reducing the stress on farming the land and to use the farming resources more effectively. Meanwhile, the ownership of the system remains with the technology provider, who is responsible for the service, maintenance of the system along with all operation costs. Hence, providers are incentivized to improve their energy efficiency to increase their profit margins.

Source: R. Evangelista and D. Karamitsos, BASE – Basel Agency for Sustainable Energy, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Buencafé	Coffee freeze drying	Colombia	Freeze drying

Overview

Buencafé is a Colombian company that produces premium soluble coffee and is part of the Colombian Coffee Growers Federation (FNC). Industrial-scale production uses freeze-drying technology. The process starts with the collection of fresh green coffee, which once roasted is ground and immersed in pure spring water to extract the soluble coffee compounds. The extract is frozen at about -5°C to preserve flavour and aroma; then, ice is removed through cryo-concentration. Finally, coffee extracts are deep-frozen at -50°C using vacuum pressures (less than one-thousandth of atmospheric pressure), followed by the remaining ice sublimation. As for the refrigeration system, since 1990, R-22 has been replaced with ammonia (R-717). This processing method allows obtaining Premium Colombian coffee.

The company has increased its energy efficiency, reducing the energy consumption per kilogram of freeze-dried coffee from 40 kWh in 2015 to 34 kWh in 2018. Thanks to the efficient use of the natural resources available and the adoption of circular economy strategies, Buencafé has been able to start substituting fossil fuels along the process. Coffee wastes and natural gas are used as energy sources for heat production, while a large portion of the electricity is supplied using a 5 MW photovoltaic system and a 2.5 MW hydropower system.

Source: FAO, 2022 and Colombian Coffee Growers Federation (FNC), 2019. Informe de Sostenibilidad 2015-2018 [In Spanish] (2019). https://federaciondecafeteros.org/app/uploads/2019/11/Informe-de-Sostenibilidad-2015-2018.pdf. Accessed 21 January 2022.

Developer	Project name	Location	Target applications / cold chain elements
Centre for Sustainable Road Freight	Digital twins	United Kingdom	Transport

Overview

The Centre for Sustainable Road Freight has developed a standard logistics and energy agent-based model that takes a given logistics demand and allows the agents to make autonomous decisions to improve their performance. The model can self-organize to develop robust and efficient logistics operations for given cold chain scenarios. The model allows developing robust design of experiments in which the rich model description of the real world can be exercised, and the sensitivity of solutions can be analysed.

Source: P. Greening, Heriot-Watt University, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
ColdHubs Limited	ColdHub	Nigeria	Cold storage, data/ monitoring

Overview

ColdHubs Ltd. is a social enterprise that designs, builds, commissions and operates solar-powered walk-in cold rooms in farm clusters, produce aggregation centres and outdoor food markets. The Hubs are used by smallholder farmers, retailers and wholesalers to store and preserve fresh fruits, vegetables and other perishable foods. In addition to deploying technology, ColdHubs educates these food supply chain actors by organizing and imparting to them comprehensive skills and knowledge on post-harvest management of perishable food using local language educational comics.

Each ColdHub includes a cold room that can fit around three tons of perishable food arranged in 150 units of 20 kilogram plastic crates stacked on the floor. ColdHubs currently serves 5,250 farmers, retailers and wholesalers using 54 installed cold rooms in 38 farms, aggregation centres and markets in Nigeria. Users pay 100 Nigerian naira ($0.26) to store one 20 kilogram returnable plastic crate per day inside the cold room – a unique pay-as-you-store Cooling-as-a-Service (CaaS) concept.

In 2020, the 54 operational ColdHubs saved 42,024 tons of food from spoilage. They increased the household income of 5,240 small farmers, retailers and wholesalers by 50 per cent, adding another $60 to the previous $60 earned, making their monthly income a total of $120, simply by eliminating the previous 50 per cent food loss. The initiative also created 66 new jobs for women, by recruiting and training them to work as hub operators and market managers in markets and farm clusters.

Source: N. Ikegwuonu, ColdHubs, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Colruyt Group	Universal cooling machine with natural refrigerant	Belgium, Luxembourg	Retail refrigeration

Overview

Colruyt Group aims to systematically replace refrigeration installations that use synthetic refrigerants with a refrigeration system that uses natural refrigerants such as propane, propylene or CO_2, across all its Bio-Planet, Colruyt, OKay, OKay Compact and Cru stores. Once the installations are replaced, Colruyt Group Belgium will have reduced its total greenhouse gas emissions 11 per cent.

Bio-Planet stores that switched to Propane Compact Chillers (from R-507 systems) have reduced their direct emissions more than 99 per cent. In terms of indirect emissions, the energy efficiency of the new cooling system is comparable to that of the previous HFC installations. When compared to the 2015 store, the 2019 upgrade's CO_2-equivalent was reduced from 80 tons per year to only 0.16 tons per year.

Source: C. Bootsveld, Colruyt Group, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Cool Coalition	National Cooling Action Plan Methodology	Global	Whole chain / broader cooling applications

Overview

Currently being piloted in Cambodia and Indonesia, the methodology charts a holistic but modular process for the development of NCAPs that covers cooling comprehensively (including various sectors such as agricultural cold chain, and end uses) and considers access to cooling for all.

Source: UNEP Cool Coalition

Developer	Project name	Location	Target applications / cold chain elements
Equatorial Power	Idjwi Island Cold chain Catalyst	Idjwi Island, South Kivu, Democratic Republic of the Congo	Cold storage, data / monitoring

Overview

Equatorial Power is piloting the development of a cold chain system on Idjwi Island to supplement demand on its 30 kW / 300 connection photovoltaic mini-grid and a 30 kW existing industrial park. A hub-and-spoke cold chain system is developed on the island, where a 5 ton ice maker is installed and powered at the industrial park for the preservation of poultry, dairy and farmed tilapia intended for export to mainland markets via a boat outfitted for iced storage. The ice maker also allows ice distribution to two other locations on the island where chest freezers hold and sell the ice. The purchase of a combination of off-grid refrigerator/freezing equipment, as well as ice boxes for fishers and smallholder dairy producers, will be financed to enable greater demand for Equatorial Power's ice maker and increase the economic benefits of the cold chain.

Source: A. Bharadwaj, C. Beland and M. Falciatori, Equatorial Power, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
FFEM (Fonds français pour l'Environnement mondial/French Facility for Global Environment)	A solar-powered cold room to help fishing ports adapt to climate change	Dakar, Senegal	Cold storage

Overview

With 718 kilometres of coastline and 600,000 people employed in the fishing sector, Senegal remains highly dependent on fishing resources. Under the effects of climate change, potential catches may see significant decline, aggravating the North/South political inequalities and threatening the population's food security. Small fishing ports are particularly susceptible to these changes.

Despite its vitality, the port of Fass Boye lacks any means of storage, meaning that wholesalers have to fetch ice every day. The development of an autonomous solar-powered cold room will allow for better fish storage, limiting losses while also reducing reliance on chemical batteries. The project benefits from FFEM aid via the Private Sector Innovation Facility (FISP).

Key objectives of the project include:

- Commissioning a solar-powered cold room in the port of Fass Boye to store fish and testing its technical operation following completion of an external study.
- Defining how the facility's governance and management will work to help enhance its use, supporting stakeholder buy-in and identifying impacts.
- Evaluating the added value of this equipment via user feedback and audits, to pursue roll-out at a larger scale.

The aim is to:

- Minimize transport movements, ice consumption and reliance on fossil fuels through the development of a solar-powered solution.
- Preserve fishing resources and reduce waste.
- Create local employment for management and security at the pilot cold room.
- Secure production resources and revenues of fish wholesalers.

Source: C. Durand, Ministère de la Transition Ecologique – France, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Flexible Power Systems	Waitrose to trial wirelessly charged electric delivery vans in London	United Kingdom	Transport

Overview

As part of its ambition to end fossil fuel use across its entire transport fleet by 2030, the supermarket chain Waitrose, working with Flexible Power Systems, was trialling at the start of 2022 a fleet of electric home delivery vans that can be charged wirelessly in London.

The project builds upon the trial of wireless charging technology for light commercial vehicles in 2021 with the City of Edinburgh Council and Heriot-Watt University, funded by the UK Government's Office for Low-Emission Vehicles through its innovation agency, Innovate UK. The vans will all be based at Waitrose St Katherine's Dock store, and Waitrose intends to expand it to other stores, if the trial is successful.

The trial involves seven Vauxhall Vivaro-e delivery vans, each fitted with a 75 kWh battery that delivers a range of up to 330 kilometres. The vans make use of a mixture of wireless and wired charging infrastructure. They are equipped with a slim charging pad on the underside and can be parked over a charging plate in the ground to begin charging. They can also be plugged in to charge overnight. The wireless charging kit is rated for 44 kW, whereas the wired chargers are 11 kW.

Wireless charging technology can provide many benefits in commercial applications, including faster starts to charging sessions, improved productivity of drivers and vehicle turnaround times, and reduced trip hazards and need for maintenance as there are no cables. They are also essential in the advent of autonomous vehicles that will have no driver to plug them in.

Source: M. Ayres, Waitrose, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Global Environment Facility (GEF) SolarChill Project	Solar Cold Storage for Vaccines and Food	Kenya, the Kingdom of eSwatini and Colombia	Cold storage

Overview

The SolarChill project was launched in 2001 to develop and deliver affordable, technically reliable, climate-friendly, solar-powered refrigeration equipment that was free from a lead-acid battery. After the initial research and development, the second phase (2017-2019) of the project funded by the GEF started, aimed at demonstrating the reliable and affordable use of the SolarChill technology in three project countries: Kenya, the Kingdom of eSwatini and Colombia. Two distinct refrigeration units were developed, Solar Chill A for the vaccine, and SolarChill B for household and commercial purposes. The GEF SolarChill Project covered:

- Comparative testing of existing brands of commercialized SolarChill A refrigerators under different climatic and operational conditions.
- Support to the production and World Health Organization certification of a SolarChill A unit by a manufacturer in a partner country.
- Laboratory and field test prototypes of SolarChill B under different climatic and operational conditions.
- Support to the production of SolarChill B in the partner countries and encouraging the marketing of SolarChill B by other manufacturers.
- Dissemination of the relevant data on both SolarChill A and B in the global off-grid appliance sector.

Source: FAO and Professor Toby Peters and Dr. Leyla Sayin

Developer	Project name	Location	Target applications / cold chain elements
Global Food Cold Chain Council (GFCCC) and UNEP OzonAction	The Cold Chain Database	Global	Whole chain / broader cooling applications

Overview

The initiative aims to develop a database model to quantify stocks, understand gaps and project scenarios of the cold chain applications at different cold chain processes through a comprehensive assessment methodology and a thorough data collection approach that captures information about technologies, refrigerants, food loss, energy, economics and operation practices. The database marks the first formal step to assist developing countries in identifying their cold chain baseline along with their consumption of relevant HCFCs or HFCs or other refrigerants. The model is designed to capture the details and specifics of each sub-sector. In addition to the main 7 sectors that are identified, 20+ sub-sectors and 50+ sub-sub-sectors are being classified within the scope of work of the database to ensure the comprehensiveness and inclusiveness of the model.

A detailed set of questionnaires has been developed to facilitate the stage-I and Stage-II data collection process. All questionnaires are also available in three languages (English, French and Spanish). The gathering activities include five main topics: 1) population and types of applications in each sub-sub-sector; 2) type, quantities, and service practices of refrigerants used for each type of application; 3) basic energy consumption data; 4) information about food loss estimates and causes; and 5) basic capital and operating expenditures (CAPEX/OPEX) of different types of facilities.

Source: UNEP and GFCCC

Developer	Project name	Location	Target applications / cold chain elements
Governments of the UK and Rwanda, Centre for Sustainable Cooling (and UK academic partners), UNEP United for Efficiency and University of Rwanda	Africa Centre of Excellence for Sustainable Cooling and Cold chain (ACES)	Rwanda/Africa plus Living Lab in Kenya	Whole chain / system approaches to cooling applications

Overview

ACES creates a world-leading collaboration among governments, academic, industry, communities and non-governmental organizations that accelerates sustainable solutions to market to simultaneously address two urgent and interconnected global development challenges: food loss and access to sustainable cold chain and cooling.

A key goal is to deliver industry the right environment, sales channels, customer financing models and support for the development, demonstration and marketing, and installation and maintenance of new technologies. Alongside demonstrating and proving refrigeration and cold chain technology in-market, ACES will help build after-sales capability, develop the techno-economic business models and financing mechanisms Including climate finance), shape policy and develop capacity through research, teaching and training programmes. The centre will serve as the hub for a network of Living Labs across Africa that demonstrate and implement solutions; the first of these is in development in Kenya.


© ACES

Source: UNEP and Professor Toby Peters

Developer	Project name	Location	Target applications / cold chain elements
Heriot-Watt University and Sustainable Energy for All (SEforALL)	Cooling for All needs assessment	Global	Whole chain / broader cooling applications

Overview

The needs assessment, developed by Heriot-Watt University and SEforALL, is a peer-reviewed tool for governments, development institutions and non-governmental organizations to assess the full spectrum of cooling needs across buildings, cities, agriculture and health, and to identify the policy, technology and finance measures to address those needs.

Source: Heriot-Watt University and Sustainable Energy for All (SEforALL)

Developer	Project name	Location	Target applications / cold chain elements
Impagro Farming Solutions	Impagro Farming Solutions	India	Whole system

Overview

Impagro Farming Solutions takes a systems approach to understand the hurdles that prevent mass adoption and utilization of decentralized cold chain technology by farmers, cooperatives, producer organizations and agribusinesses. The company developed a framework to identify actions to be taken before, during and after crops enter the farm-level cold chain. The aim is to use the framework to develop sustainable business models to operate first-mile supply chains equipped with sustainable cooling technologies.

Source: FAO and Professor Toby Peters and Dr. Leyla Sayin

Developer	Project name	Location	Target applications / cold chain elements
InspiraFarms	Solar Cold Storage and Processing in Rwanda	Rwanda	Cold storage, food processing

Overview

In 2018, InspiraFarms commissioned 10 modular, solar-powered food processing and refrigerated storage facilities in six districts across four of the five provinces of Rwanda. Each facility has a total area of 150 square metres, including cold storage, a processing area, an aggregation area, and administrative and hygiene spaces. Facilities run completely off-grid and in compliance with food safety standards.

The main impact of the system is the increased availability and access to cold storage for fresh produce. In Rwanda, the cold rooms are expected to be used for fresh vegetables and fruits as well as for flowers. The installed facilities provide access to the cold chain for more than 100,000 smallholder farmers. Additionally, the availability of cold storage has prompted farmers to produce high-value crops for both local and export markets.

Source: FAO and Professor Toby Peters and Dr. Leyla Sayin

Developer	Project name	Location	Target applications / cold chain elements
International Center for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Institute of Tunisia (INRAT)	An innovative solar-powered milk cooling solution for the higher efficiency of the dairy sub-sector in Tunisia	Tunisia	Milk chiller

Overview

An innovative solar-powered milk cooling system designed by the University of Hohenheim has been installed in Tunisia. The primary impact of introducing the solar-powered chiller was an increase in the quantity of milk sold from isolated farms. Due to the availability of cooling capacity on the farm, farmers in isolated areas could keep milk cold overnight and sell it to the collection centre the next morning. In the test farm, the farmers had around 15 litres of uncollected milk every evening. The availability of the solar chiller allowed the farmer to earn an additional 3.75 British pounds per day. A second major benefit of the chiller is reduced carbon emissions.

With the solar cooling system, the milk arrives at the collecting centre after two hours with a temperature of 15°C instead of 30°C. The electricity required to cool 1 litre of milk from 30°C to 4°C (assuming a mean co-efficient of performance of 1 for the heat pump) is around 0.03 kWh per litre. When comparing solar cooling systems with traditional grid-connected systems and considering Tunisia's electricity emission factor (0.572 kilograms of CO_2-equivalent per kWh), a decrease of 9.7 grams of CO_2-equivalent per litre could be obtained with the solar milk cooling. An average milk collecting centre cools around 40,000 litres of milk per day. With this volume, daily carbon emissions would be around 686 kilograms of CO_2-equivalent. If all farmers delivering milk to the centre used a solar cooling system, daily carbon emissions could be reduced by more than half, to around 297 kilograms of CO_2-equivalent.

Source: FAO

Developer	Project name	Location	Target applications / cold chain elements
International Finance Corporation (IFC) in partnership with UK Government's Department of Business, Energy & Industrial Strategy (BEIS)	Sigma & Promethean	Colombia and Mexico	Cold storage

Overview

The IFC is supporting a partnership between the Indian company Promethean Power Systems, which designs and manufactures cold storage systems for off-grid and partially electrified locations, and the food company Sigma in Mexico to test a solution that converts electrical energy into cold energy, without the need to mount a condensing unit on a refrigerated vehicle. The aim is to reduce diesel fuel consumption and food losses due to poor temperature-control. The project was launched in May 2021 and was expected to be completed by October 2021.

Source: S. Tanatar, IFC and L. Kanji, UK BEIS, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
International Finance Corporation (IFC) in partnership with UK Government's Department of Business, Energy & Industrial Strategy (BEIS)	Addressing the Missing Link Along India's Retail Cold Chain	India	Cold storage, market connectivity

Overview

This project aims to address the issue of high operating costs for existing temperature-controlled secondary distribution centres and to develop the business case for increasing the use of non-fossil-based energy sources to power these last-mile distribution centres, thus making them more cost-efficient and environmentally sustainable. The project will be implemented in two phases: Phase 1 will work with a leading e-commerce company, BigBasket, to test and validate select technologies, and Phase 2 will identify, replicate and scale a suite of potential solutions across the retail sector. The impacts include:

- Cost savings and reduced operational expenses through more efficient cold chain options as compared with traditional refrigeration.
- Greenhouse gas emissions reduced or avoided through use of sustainable cooling technologies that use renewable energy sources (i.e., thermal energy storage, phase change material, biomass).
- Other beneficiaries include urban retail consumers who will benefit from improved quantity and quality of perishables due to better maintenance of cold room temperatures.
- Reduced food waste, resulting in lower consumer prices, less hunger and improved food security.

As part of the project, five GreenCHILL cold rooms were initially installed at the BigBasket Distribution Centre in Bengaluru, and due to satisfactory performance four more systems were installed in April-June 2021. Using GreenCHILL enabled a reduction of on-grid (i.e., fossil fuel-based) energy usage of up to 90 per cent. Following the introduction of GreenCHILL, the baseline daily average electricity consumption fell from 83 kWh to only 8 kWh. The difference in on-grid electricity consumption is replaced by around 100 kilograms of biomass fuel per day.

The main issue faced during installation and operation of the technology was the need for trained personnel to carry out activities such as continuous monitoring, data logging, fuel feeding and overall operation of the system.

Source: S. Tanatar, IFC and L. Kanji, UK BEIS, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Oorja Development Solutions India Private Limited	Oonnayan: Solar-powered Cooling-as-a-Service for Smallholder Farmers	India	Precooling, cold storage

Overview

In March 2021, Oorja launched its third integrated clean energy service "Oonnayan". It offers Cooling-as-a-Service under a pay-per-use model without any technology acquisition cost. Under this model, Oorja finances and installs 5 ton solar cold storages for use by 30-50 farmers, depending on the size of their landholding and type of horticultural produce. Farmers can store their perishable produce on a per-crate-per-day basis within a cold room installed conveniently at the market gate. They can use the service without bearing any upfront cost for technology acquisition and only pay for the amount of produce stored and an initial membership fee of 1,000 Indian rupees to ensure buy-in. The Oonnayan cooling service aims to help smallholders and marginalized farmers extend the quality and shelf life of their produce and realize higher market prices, increasing incomes an expected 50 per cent or more.

For the technology configuration, Oorja partnered with Ecozen and, in a pilot installation (in Muzaffarpur, Bihar) tested Ecozen's Ecofrost 5 ton portable cold room. This pilot serves as a demonstration and will enable Oorja to demonstrate the viability of the Cooling-as-a-Service model, before scaling up to fill an identified market gap.

Source: C. Chambon and A. Saraogi, Oorja Development Solutions India Private Limited, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Rabobank	The Cool Move	Kenya and subsequently Sub-Saharan Africa	Cold storage, aggregation, data/ monitoring, market connectivity

Overview

The World Bank, FAO Investment Center and Rabobank are working together on developing "The Cool Move". It seeks to increase high-quality (first-mile) cold chain accessibility and use in rural areas in emerging markets in an economically viable way, combined with suitable finance solutions and investments. The Cool Move aims at an integrated value chain approach that strives to professionalize the whole value chain to bring all actors to an equal level of competitiveness. This allows all actors to compete in local, domestic and global markets. The Cool Move proposes involving both the supply side (farmer organizations and cold chain providers) and the demand side (aggregators and off-takers), creating a viable business case for all actors to drive cold storage development and create the foundation for a scalable solution. The objectives include:

- Reduction of post-harvest losses
- Improved access to cold chain for smallholders
- Safeguarding farmers' incomes, by increasing access to off-takers and enhancing market linkages
- Improved food quality, meeting food standards and therefore improving food security and food safety
- Reduction of greenhouse gas emissions by preventing food losses
- Empowering small and medium enterprises (storage managers, logistics providers, producers, traders and retailers) and creating off farm-jobs for youth
- Raising investments and implementing finance solutions for cold chain and other agro-logistics
- Deploying technology and scaling up successful business models.

Source: L. Verhofstad, Rabobank, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Savanna Circuit Tech Ltd	Solar Milk Transport in Kenya	Kenya	Motorcycle-mounted milk chiller

Overview

Savanna Circuit developed an affordable milk chilling-on-transit system to transport milk safely. The technology consists of a solar-powered milk storage tank mounted on a motorcycle. The company uses aluminium tanks connected to a solar panel to produce the electricity to cool the milk. The service requires farmers to download an app that keeps track of how much milk is sold by each farmer. The company also organizes the farmers into groups to operate the equipment at near-full capacity. Farmers notify the company when the milk needs to be transported to bulkers. The milk is then weighed, tested for its pH value and cooled to 4°C for the duration of transit until it reaches the bulking stations. Each cooling unit has a capacity of 120 litres but can be customized to capacities of up to 1,000 litres. The business serves more than 1,000 households and has increased their incomes up to 37 per cent. The company is active in two of the four target regions in Kenya.

Source: S. Mettenleiter and V. Torres-Toledo, SelfChill, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
SELCO Foundation	Accelerating decentralized cold chain access for small and marginal farmers	India	Cold storage, market connectivity

Overview

The project aims to:

- Improve access to decentralized cold chain solutions for small, marginal farmers (close to the farm gate), thereby minimizing post-harvest losses from wastage and distress sales (using innovations on negative temperature, reefer vans, and replication and scale of well-tested positive temperature cold stores of 2-15 ton capacity).
- Unlock barriers to scale by enabling better access to credit and government support alongside capacity-building of end users for better use of the solution.
- Facilitate integration of decentralized sustainably powered cold chain solutions into local, state and national government priorities for agriculture and allied sectors (across districts and states).

SELCO Foundation has directly facilitated more than 30 implementations of positive-temperature cold storage units and has more than 60 units in the pipeline. Technology partners such as Inficold, Ecozen and Cool Crop have established businesses to manufacture and sell cold storage units. Across India, more than 350 units have been installed through different technology vendors.

Source: H. Jaffer and S. Rajagopal, Selco Foundation, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Thailand	Warehouse, Silo and Cold Storage Act	Thailand	Whole chain

Overview

The Act was drafted with the aim of encouraging the private sector to invest more in warehouse, silo and cold storage facilities to help strengthen the distribution of fisheries and agricultural products. It reduces both the approval process and the time taken to obtain a licence, to give entrepreneurs easier access to such facilities. The Director General of Internal Trade is now the approving authority, rather than the Commerce Minister, which previously approved every investment. The Act is also being used to monitor the operations of cold storage businesses, with provisions for penalizing defaulters and restricting illegal and unorganized facilities.

Source: Professor Toby Peters and Dr. Leyla Sayin

Developer	Project name	Location	Target applications / cold chain elements
UN Development Programme (UNDP)	Demonstration projects for using CO_2-based technology in the commercial refrigeration sector	Republic of Moldova	Cold storage, retail refrigeration

Overview

One of the components of the joint UNDP and Government of Moldova HCFC Phase-Out Management Plan (HPMP) Stage II programme refers to the demonstration of new technologies (based on natural refrigerants) in the commercial refrigeration sector. HPMP-II supports the demonstration projects in the refrigeration and air-conditioning sector (commercial refrigeration, chill cabinets, cold storage and food processing, industrial refrigeration, large air-conditioning and chiller systems) with the aim of applying modern natural refrigerant technologies such as CO_2 in the Republic of Moldova and building local practical experience and end-user confidence in their application.

For this purpose, a call for expression of interest was published on the UNDP website. Applications were received from Forward International SRL and STS Trading. A selection process confirmed that both companies met the eligibility criteria and accumulated satisfactory points to enable them to receive financial support for new and innovative solutions in the cold chain sector, piloting refrigeration technology based on natural refrigerants (CO_2) in the commercial sector.

Source: Professor Toby Peters and Dr. Leyla Sayin

Developer	Project name	Location	Target applications / cold chain elements
UNDP and Ministry of Nature Protection of Belarus	Initial Capacity Building for HCFC Phase-out in Countries with Economies in Transition	Belarus	Cold storage, food processing

Overview

Belarus has had a steady phase-out of HCFCs from 2010 onwards as a result of the initial capacity-building support from the Global Environment Facility (GEF) and UNDP. There is still a demand for HCFC-22, which the new project will address by ensuring that the phase-out is sustainable over the mid to long term.

Belarus is committed to promoting zero-ODP, low-GWP energy-efficient technologies in its quest to eliminate its dependence on HCFC-22. The main barrier to achieving the phase-out, until recently, has been the non-availability of commercially available, cost-effective low-GWP substitutes for HCFC-22. HFC-based technologies, which are zero ODP, but high GWP, have been gradually introduced since they dominate in the global market. The initial regional HCFC phase-out project, financed by the GEF and supported by UNDP, has been instrumental in building foundations for training and improving the skills of specialists to work with HCFC-free technologies, specifically with water absorption, ammonia and R-290 (propane) in split air-conditioning units.

Source: X. Zhou, UNDP, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
UNEP United for Efficiency (U4E)	Refrigerators transition to energy-efficient and climate-friendly cooling in Africa	Africa (East African Community (EAC), Southern African Development Community (SADC), Ghana, Senegal and Rwanda	Cold storage

Overview

The project will implement U4E's Integrated Policy approach with a suite of tools and resources to support African countries in taking action through national strategies, policies and deployment activities for energy-efficient and climate-friendly refrigerators. The objectives include:

- Provide governments with evidence, based on market data, on the savings potential of deploying energy-efficient and climate-friendly refrigerators.
- Equip government officials with capacity and guidelines to set ambitious MEPS and labelling and to use low-GWP refrigerants, improve waste management of refrigerators, and address imports of used refrigerators.
- Foster regional harmonization to facilitate monitoring and compliance of policies and to leverage economies of scale to reduce upfront costs.
- Develop financial mechanisms and sustainable procurement schemes to accelerate the adoption of energy-efficient and climate-friendly refrigerators.
- Raise awareness of the importance of sustainable cooling solutions.

Source: UNEP

Developer	Project name	Location	Target applications / cold chain elements
UNEP United for Efficiency	Model Regulation Guidelines	Global	Whole chain / broader cooling applications

Overview

This voluntary guidance was developed to assist governments in developing and emerging economies that are considering a regulatory or legislative framework for minimum energy performance standards and energy labels.

Source: UNEP

Developer	Project name	Location	Target applications / cold chain elements
United Nations Industrial Development Organization (UNIDO)	Demonstration project for the introduction of trans-critical CO_2 refrigeration technology for supermarkets in Argentina	Argentina	Retail refrigeration

Overview

From 2010 to 2016, the five largest Argentine supermarket chains grew by 63 per cent (City of Buenos Aires 2011). During that period, R-22, an HCFC refrigerant with a high GWP of 1,760, was the most widely used refrigerant for retail food refrigeration systems, particularly in the supermarket sector. Given the sector's high reliance on R-22, the HCFC Phase-out Management Plan of Argentina prioritized phasing out HCFC refrigerant use in supermarkets.

In May 2016, the Executive Committee of the Multilateral Fund approved a project in Argentina to demonstrate the possibility of phasing out HCFCs by leapfrogging the HFC conversion step and introducing technologies based on natural refrigerants. The 30-month project, implemented by UNIDO with a budget of $527,169, aimed to evaluate the performance and energy efficiency of trans-critical CO_2 technology and to identify incentives and barriers related to an upgrade to this technology.

Following technical requirements provided by UNIDO and the National Ozone Unit of Argentina (OPROZ), a commercial refrigeration equipment manufacturing company, EPTA Argentina S.A., developed a CO_2 trans-critical system design with assistance from its design headquarters in Italy and the United Kingdom. The pilot project took place at a supermarket in the town of Lincoln, in Buenos Aires Province. The supermarket's two central refrigeration systems – one for low and one for medium temperatures – relied on R-22. In addition, a number of self-contained freezer units (islands and upright reach-in cabinets) operated using R-404A, which has an even higher GWP of 3,920.

During the first 11 months of the trial period, the CO_2 trans-critical system consumed 28 per cent less electricity than did the supermarket's pre-project baseline equipment (UNIDO 2018). In addition, the project led to significant direct emission reductions due to the much lower GWP and refrigerant leakage of the new system (Climate Transparency 2019). Based on these promising results, the recipient company, La Anónima, adopted trans-critical CO_2 as the default technology for its new branches and for refurbishing existing ones, where feasible. From 2016 to 2020, seven different companies adopted CO_2 trans-critical systems at a total of 13 supermarkets in Argentina. The same vendor also installed three such systems in Chile and nine in Ecuador from 2017 to 2020 (UNIDO 2018).

Source: UNIDO

Developer	Project name	Location	Target applications / cold chain elements
UNIDO	Demonstration of non-HFC alternatives to HCFC-22 in retail installations in countries with high ambient temperatures: The first CO_2-refrigerated supermarket in the Middle East (Jordan)	Jordan	Retail refrigeration

Overview

With funding from the Climate and Clean Air Coalition, UNIDO implemented in 2018 a pilot project using natural refrigerants at the Al Salam supermarket in Amman, Jordan, in collaboration with the Ministry of Environment of Jordan and technology providers from Jordan and Italy. Under the project, the Middle East's very first trans-critical CO_2 refrigeration system in a supermarket was implemented. Through the full-scale replacement of the supermarket's existing installations that used R-22, the project demonstrated the feasibility of a CO_2 trans-critical system in retail refrigeration in a country with high ambient temperatures.

The aim of the project was to evaluate the performance and energy efficiency of systems using CO_2 as the working fluid, as an alternative to the R-22 refrigerant that is still often used in retail installations in many developing countries. The system, installed in January 2018, is a CO_2 trans-critical booster system with parallel compression. To ensure high efficiency even during the hottest months, the system integrates state-of-the-art ejector technology. It also features non-superheated evaporator technology for both chilled and frozen food cabinets and storage rooms. The waste heat from the system can be recovered for hot sanitary water supply, saving further energy overall.

Compared to the previous system, the trans-critical CO_2 refrigeration unit results in a reduction in annual electricity demand of 40,000 kWh, which corresponds to a CO_2 emission reduction of around 32 tons per year. The direct emission reduction with the replacement of R-22 is around 35 tons of CO_2 equivalent annually. The success of the system has enabled a better understanding of the applicability of the technology in countries with high ambient temperatures and has promoted innovation within the national industry.

Source: UNIDO

Developer	Project name	Location	Target applications / cold chain elements
WorldFish	Solar powered freezers for fish storage	Solomon Islands	Freezer for fish

Overview

The project is a community-led initiative to implement simple solar-powered fish chillers to reduce fish losses and increase incomes of local women fish farmers.

Source: FAO

Developer	Project name	Location	Target applications / cold chain elements
WWF-Kenya	Kigali Cooling Efficiency project – Cool solutions to chilling prospects: piloting efficient cooling for sustainable seafood supply chains in East Africa	Kenya	Cold storage

Overview

The project aimed to pilot the use of clean, efficient cold storage facilities through selected model Beach Management Units (BMUs) in coastal Kenya to showcase the untapped opportunity of off-grid cooling solutions and minimize post-harvest losses for improved income opportunities by fishers. The objectives include:

- Assess the key constraints along the fisheries value chain on the Kenyan coast and identify opportunities to reduce post-harvest losses through access to clean, efficient cooling.
- Pilot the use of efficient cooling solutions in select BMUs, building the capacity of those management units to maximize the impact of cooling on their livelihoods.
- Engage local government to create an enabling regulatory environment for the adoption of efficient cooling in Kenya's coastal fisheries.
- Document and communicate the findings of the pilot project.

The project achieved a reduction in post-harvest fish losses based on the assessment data collected from the department of fisheries for the settlement of Ngomeni:

Ngomeni (2020)	Jan	Feb	Mar	Apr	May	Jun	Jul	Sept	Oct	Nov	Dec
Fish Catch (kg)	50,500	66,400	73,600	65,600	9,239	9,842	3,134	14,456	7,960	14,275	6,419
Fish Loss (kg)	10,000	20,600	11,200	8,000	1,156	1,078	1,361	215	159	199	234

Source: L. Dali and I. Mwaura, World Wide Fund For Nature Kenya, personal communication, August 2021

Developer	Project name	Location	Target applications / cold chain elements
Italy	Integrated policy frameworks to promote food waste reduction and efficient cold chain development measures – the experience under the Italian Law n. 166/2017 to tackle food loss and waste	Italy	Whole chain

Overview

Italy is strongly engaged to tackle food loss and waste and to show global leadership in the field in order to contribute to the UN 2030 Agenda, in the framework of the evolving strategies and provisions also at the EU level. This commitment has been enshrined in the national legislation by the Law n. 166/2016 (Legge Gadda) concerning the donation and distribution of food and pharmaceutical products for social solidarity purposes and reduction of waste. This contributes to the overall objectives of the national programme for waste prevention, and promotes waste recycling and use.

The Law embeds several elements of the national plan against food waste (PINPAS) as it aims to facilitate the recovery and donation of food and pharmaceutical products. It defines food waste as the aggregate of still edible food products discarded from the agri-food chain for commercial and aesthetic reasons or due to proximity to the expiration date. Market operators are therefore allowed to freely provide surpluses to donation entities that pursue social and not-for-profit solidarity activities, but also to use these as animal feed and for self-composting with a view to reduce food waste to the maximum extent.

The Law Gadda provides for an integrated policy scheme by establishing coordinated competence of implementation and enforcement among all relevant line ministries. The Ministry of Ecological Transition, in coordination with the Ministry of Agriculture and Forestry and the Ministry of Health, is responsible for promoting information campaigns to incentivize the prevention of food waste production concerning best practices in the context of the restaurant business. In a multi-level approach in line with articles 1 and 6 of the Law, the competent public administrations have a set of specific powers and instruments to promote initiatives targeted at the reuse of surpluses, including, among others, financial instruments, logistic measures, and the establishment of criteria in the context of public procurement and tender activities (quantitative targets, educational measures, framework/programme agreements).

A number of specific measures could be planned to combine the implementation of the goals set out under the Law n. 166/2016 to reduce overall food waste, including through promoting the development and efficient streamlining of cold chains.

For example, in the context of the national coordination between relevant line ministries and other relevant authorities and stakeholders, aimed at devising ad hoc measures to implement the Law n. 166/2016, in 2018, the Italian Ministry of the Ecological Transition (former Ministry for the Environment, Land and Sea) launched a bid to co-finance projects targeted at reducing food waste through management of food surpluses by means of social solidarity activities. This is the so-called Bando Eccedenze, which includes cold chain-specific technologies.

The bid aimed at providing co-financing to integrated projects for the management of food surpluses throughout food chains, including supply, transport, storage, conservation, processing and distribution, by foreseeing the purchase of relevant equipment required to contribute to food waste reduction by means of social solidarity actions.

This project allowed in particular the provision of isothermal or insulated refrigerated vehicles, isothermal containers for food transport, blast chillers, thermal food trolleys, cold rooms, refrigerators and freezers. Such equipment allows for adequate conservation of fresh food products that are otherwise perishable. This would ensure their safe management and combine social and environmental aims through quality food redistribution to the poorest sectors of society and food waste reduction.

Source: Source: F. Mannoni, Ministry for Ecological Transition – Italy, personal communication, August 2021

Technologies/Systems

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Ancar India Pvt. Ltd.	Super-Efficient Cold Room/ Storage	TRL 4, MRL 3	Cold storage	Off-grid/ On-grid	Not specified

Impact

- Up to 50 per cent power savings with thermal energy storage.
- Ceramic net to improve the air quality and safe ionization for healthy air inside the cold room/storage and additional 15 to 20 per cent power savings.
- Efforts under way to further reduce energy consumption and improve affordability by using R-718 (water) and replacing thermal energy storage with a new technology*.

*Details not provided due to confidentiality.

Source: A. Shaikh, Ancar India Pvt. Ltd, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
CAREL Industries SpA	Heos Sistema	TRL 9, MRL 10	Food retail refrigeration	On-grid	Not specified

Impact

Compared to ON-OFF water loop systems:

- Calculated energy savings of 39 per cent.
- Improved temperature stability, meaning higher food preservation and longer shelf life.

Source: R. Simonetti, CAREL Industries SpA, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
CAREL Industries SpA	Hecu Sistema	TRL 9, MRL 10	Food retail refrigeration	On-grid	R-410A

Impact

The operating conditions of a hypermarket near Guangzhou, China equipped with seven Heos Sistema units with a total cooling capacity of 63 kW were compared against a traditional store running R-404A ON-OFF units.

- Calculated energy savings of 28 per cent per ton.
- Return on investment (ROI) estimated as less than 16 months.

Source: R. Simonetti, CAREL Industries SpA, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Coldway Techno-logies	Solid gas ammonia sorption technology (natural refrigerant)	TRL 10, MRL 10	Transport (large and smaller trucks, smaller containers for delivery at one address)	Can be re-charged with an external heat input from a variety of energy sources	R-717

Impact

As of September 2021, Coldway Technologies had deployed 1,500 units in 10 countries (mostly in Europe).

- Works on the principle of a basic chemical reaction between ammonia and a mixture of salts and graphite, all contained in stainless steel cylinders.
- Phase 1: On opening the valve, the ammonia evaporates inside the tank and produces refrigeration, while the gas is absorbed by the salts in the reactor thus generating heat. This immediate production of cold and heat can have an amplitude of -40°C to over 200°C. The production of heat and cold can be activated anytime, anywhere and without the need to plug in.
- Phase 2: Once the ammonia has evaporated entirely, the production of heat and cold stops and the system can be recharged with an external heat input from a variety of energy sources – electric, solar, industrial heat recovery, etc. – which promotes condensation of the ammonia. Once regenerated, the solid gas sorption system will keep the energy stored, ready to be used again.
- On a 2.5 cubic metre vehicle with a conventional diesel engine, the system enables saving 5.3 tons of CO_2 emissions per year. On an electric vehicle, the system can save 26 tons of CO_2 emissions per year.

Source: D. Tadiotto, Coldway Technologies, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Danfoss	Sustainable cooling with intermittent power supply	TRL 5, MRL 8	Refrigeration at farm; cold storage; waste heat recovery	Off-grid solar	Not specified

Impact

- Improved food quality
- Food loss reduction
- Robust operation
- Reduced greenhouse gas emissions
- Increased food production
- Improved resilience with thermal energy storage (ice)

Source: T. Funder-Kristensen, Danfoss, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Devidayal Solar Solutions Pvt. Ltd.	Solar freezer solution for tribal women to store fruit pulp	TRL 7, MRL 10	Cold storage	Off-grid solar	Not specified

Impact

- Reduced gender inequality, with all project beneficiaries being women from rural and tribal areas.
- Increase in the fruit pulp rate from 4-5 Indian rupees per kilogram to 12 Indian rupees per kilogram following installation, as the quality of the produce can now be maintained.
- Increase in the production capacity to 2.5 times that of the last season following installation, and the company plans to sell its products online through different platforms as production is increased.
- The focus product is fruit pulp, but the company also offers other value-added products like fruit milkshakes, fruit ice cream, seed powder and tea; it is also working to develop new products in the vegetable segment.
- An independent impact assessment is under way, but it is estimated that more than 300 seasonal jobs have been created for women in the tribal areas.

Source: T. Devidayal, Devidayal Solar Solutions Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Ecozen Solutions Pvt. Ltd.	Ecofrost	TRL 9, MRL 10	Cold storage	Off-grid solar	R-407F

Impact

Based on the 300 square metre unit installed in 2018 in Veguru Village, India:

- Net income of farmers who have access to the Ecofrost Solar Cold Room is almost 63 per cent higher than for those who do not.
- Lowest price for commodities of farmers who have access to Ecofrost Solar Cold Room is 5,000 Indian rupees per quintal compared to 2,000 Indian rupees per quintal for those who do not.
- The unit helped reduce 516.16 kilograms of CO_2 emissions per year.
- With thermal back-up technology, it saves 189.07 litres of diesel use per year.
- Flexibility with various business models: upfront purchase, lease or rental, or community model.

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Source: R. Dolare, Ecozen Solutions Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Eja-Ice	Solar-powered freezer Solar Power Cooling Tricycle for Last Mile Delivery	TRL 9, MRL 9	Freezer for fish/chicken, yogurt, ice cream and milk distribution	Off-grid solar	R600a

Impact

Eja-Ice offers solar-powered freezers to women in the fisheries supply chain in Nigeria through a lease-to-own scheme to enable inclusion through asset acquisition. These assets give women a chance to trade sustainably and support their families and offer nutritional items such as frozen fish and chicken. Eja-Ice further assists women to reduce their exposure to risks by providing technology risk mitigation measures such as 36 months technical support and insurance coverage; burglary, fire, and credit life insurance. Eja-Ice also offers display chillers and ice cream freezers to support the dairy foods sector.

Furthermore, Eja-Ice offers solar-powered mobility solutions with active cooling (-20°C) to support last-mile cold chain needs for manufacturers along with a fleet management tool to help mitigate waste and enable just-in-time manufacturing for businesses.

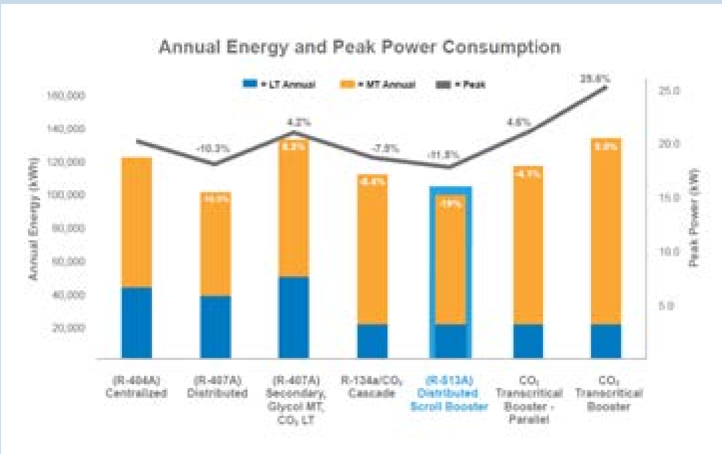
Source: Y. Bilesanmi, Eja-Ice, personal communication, August 2021

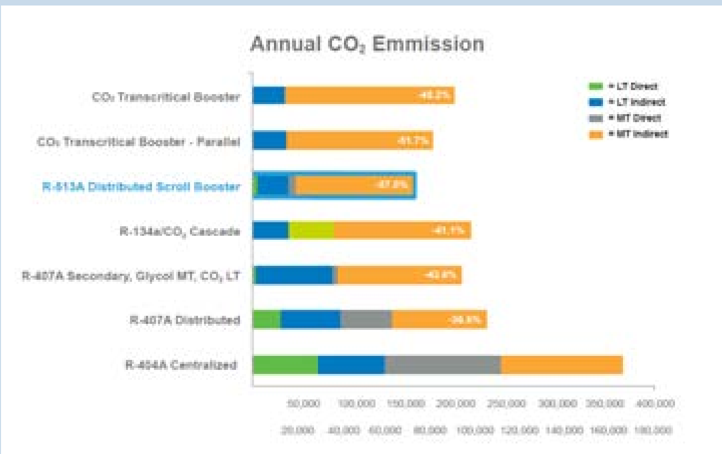
Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Emerson	A Novel Distributed Scroll Booster Architecture for Supermarket Refrigeration	TRL 7, MRL 7	Retail refrigeration	On-grid	R-513A (with future compatibility with A2L refrigerants such as R-516A and R-1234yf)

Impact

Compared to distributed systems, the unit provides benefits including:

- Reduced refrigerant charge.
- Higher system efficiencies.
- Ability to use common refrigerants and components that technicians are familiar with.
- Lower leak rates.
- Future compatibility with A2L refrigerants such as R-516A and R-1234yf.





Source: A. Patenaude and R. Rajendran, Emerson Commercial & Residential Solutions, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Evaptainer	Decoupling refrigeration from electricity	TRL 9, MRL 10	Cold storage	Off-grid	N/A

Impact

Evaptainer is a low-cost, electricity-free mobile refrigeration unit that uses evaporative cooling to keep perishable produce cool. Evaptainers make use of their patented PhaseTek™ membrane technology that enables and enhances the evaporative cooling. The technology becomes activated when the internal reservoir is filled with water. The walls of the device then begin to draw out heat from the interior of the device through evaporative cooling.

Evaporative cooling systems are especially effective in regions with hot, dry climates, are comparatively inexpensive to run, and are a good alternative to traditional refrigerant-based active cooling systems.

Source: UNEP

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Koolboks	Refrigeration (Ice thermal storage)	N/A	Food retail refrigeration	Off-grid solar	R-600a

Impact

The Koolboks freezer uses phase change material for energy conservation and optimization. It contains a minimum of 10 litres of phase change material depending on the size of the freezer.

- Ice thermal storage: The Ice batteries when activated retain cold energy and thus reduce the amount of energy that the compressor requires to cool down the freezer, drastically improving the compressor’s energy efficiency. The Ice batteries also help maintain the cabinet temperature for 4 to 7 days.

  Koolboks analyses show that the ice batteries store energy equivalent to:
  - 12-volt 150ah lead-acid battery for the 158 litre freezer
  - 12-volt 200ah lead-acid battery for the 208 litre freezer
  - 12-volt 220ah lead-acid battery for the 538 litre freezer.
- The compressor uses a low start-up torque technology, meaning that low start-up power is required to start up and run the refrigeration circuit effectively.
- The 158 litre and 208 litre freezers have an insulation thickness of 105 millimetres and double gaskets to enhance effective cold energy retention.
- Koolboks has adopted the lease-to-own business model, enabling customers to enjoy full access to affordable off-grid refrigerator units while paying in small instalments. This model works with a Pay-As-You-Go (PAYG) technology that is enabled by using mobile money and GSM-based machine-to-machine connectivity to remotely control and monitor the refrigerators’ usage, billing and performance.
- Koolbox aims to reduce carbon emission in Nigeria by 4,080 tons by 2023 by replacing 16,644 non-efficient freezers. By 2026, it aims to reduce carbon emission by 31,872 tons by replacing 130,000 non-efficient freezers.

Source: A. Dominic, Koolboks, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
New Leaf Dynamic Technolo-gies Private Limited	Green CHILL biomass-powered cold rooms	TRL 9, MRL 10	Cold storage	Off-grid biomass	R-717

Impact

Rather than electricity or fossil fuels, GreenCHILL uses biomass to generate cooling using an adsorption refrigeration technology that uses a solution of water and R-717 as refrigerant with zero GWP. The adsorption cycle is powered by hot water that is provided through a boiler unit that uses biomass for the heat source. GreenCHILL's system can be integrated with any standard industrial grade 10-20 ton cold room, up to 150 tons of capacity, that can be used as cold storage, precooler, ripening chamber or milk chiller. GreenCHILL replaces a conventional direct expansion system and runs independently from grid electricity, solar or a diesel generating set. With minimal moving parts, the system is silent and has very low maintenance requirements.

New Leaf has installed 800 tons of cold storage space to-date, benefiting more than 5,000 farmers across India, which serve as a marketing platform for perishable produce from farms, generating an additional income of $6,000 per installation each year. New Leaf has also trained more than 200 farmers in post-harvest management with the aim to reduce post-harvest losses below 5 per cent from more than 30 per cent currently. Moreover, New Leaf trains and employs local women and youth to manage the GreenCHILL operations daily, thereby generating income for three persons per installation and empowering women who are engaged in the agriculture sector.

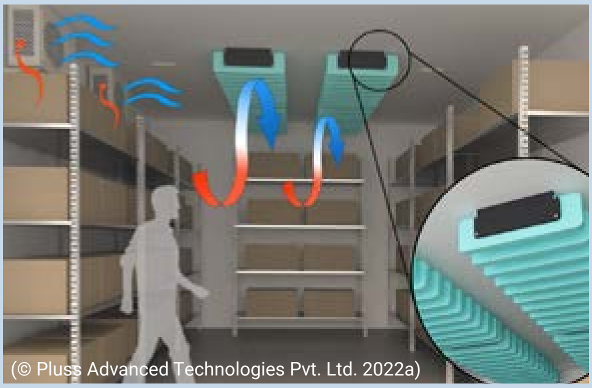
One GreenCHILL saves an estimated 40 tons of greenhouse gas emissions per year by displacing the predominantly coal-powered thermal grid with carbon-neutral locally available biomass. It provides savings of around 4,500 units of electricity per month for a 20 ton cold room.

Source: A. Agarwal, New Leaf Dynamic Technologies (P) LTD, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Pluss Advanced Technologies Pvt. Ltd.	Mass Effekt™	TRL 9, MRL 9	Phase change material (PCM)-filled HDPE bottles for cold storage/ warehouse	Passive	Not specified

Impact

- Reduces energy consumption of the refrigeration system by up to 25 per cent.
- Provides a high return on investment (ROI) with payback less than three years.
- Increases efficiency via a thermal management system.
- Reduces dependency on a power source.
- Reduces reliance on fossil fuels.
- Shifts peak power loads to off-peak hours.
- Provides back-up for critical temperature applications.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Source: S. Jain, Pluss Advanced Technologies Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Pluss Advanced Techno-logies Pvt. Ltd.	PronGo® last mile delivery solution	TRL 9, MRL 9	Insulated box with PCM-filled bottles/ pouches for last-mile delivery	Passive	Not specified

Impact

- Aims to replace single-use solutions with PronGO®, which is reusable for around three years and can be recycled easily at the end of life, reducing the wastage created by single-use EPS and gel packs and driving down the overall supply chain costs.
- Reduced food wastage during last-mile deliveries; increased income for farmers.
- Enables part-load shipment, so that products that need different temperatures can be shipped together in the same vehicle, leveraging the box-level temperature difference.
- Increases the distribution radius with higher temperature back-up.

Source: S. Jain, Pluss Advanced Technologies Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Pluss Advanced Techno-logies Pvt. Ltd.	Hybrid freezer with thermal energy storage to increase energy efficiency	TRL 9, MRL 10	Chest freezer and cooler with PCM	On-grid	Not specified

Impact

- Provides 12-16 hours of back-up.
- Reduced food loss/waste; increased income for farmers.
- Helps with load balancing and peak shaving during high demand periods.
- Energy cost savings up to 2,640 Indian rupees per month due to reduced use of diesel during power outages (assuming outage of 16 hours a day).

Source: S. Jain, Pluss Advanced Technologies Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Pluss Advanced Techno-logies Pvt. Ltd.	PCM-based reefer truck	TRL 9, MRL 8	Reefer truck refrigeration unit	Passive	Not specified

Impact

- ThermoTab™ active PCM plates maintain the temperature inside the container for 10 to 12 hours.
- Provides 100 per cent fossil fuel-free refrigeration during transport, reducing greenhouse gas emissions.
- Reduced food loss; increased income for farmers.
- Improved market connectivity for farmers.
- Reduces operational costs up to 90 per cent.

Source: S. Jain, Pluss Advanced Technologies Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Pluss Advanced Techno-logies Pvt. Ltd.	100% Off-grid PCM based Solar Cold Room	TRL 9, MRL 9	PCM-based Solar Cold Room	Off-grid solar	Not specified

Impact

- ThermoTab™ active PCM plates maintain the temperature inside the cold room for 18 to 20 hours.
- Reduced diesel consumption.
- Grid-independent, renewable energy solution, reducing greenhouse gas emissions.
- Reduced food loss up to 80 per cent; expanded shelf life up to 10 days; increased income for farmers.
- Overall cost reduction in supply chain, from farm to market.

Source: S. Jain, Pluss Advanced Technologies Pvt. Ltd., personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Promethean Power Systems	Micro Can Chiller	TRL 9, MRL 10	Milk chiller	Off-grid solar	Not specified

Impact

- Improved quality of milk collected from villages.
- Increased access for smallholder farmers to organized markets.
- Reduce diesel usage with thermal energy storage.
- Reduced 1,250 kilograms of carbon per year (considering equivalent equipment running with diesel generator back-up for 50 per cent of the time).
- Flexibility with various business models: direct sales, lease model or pay-per-use model.

Source: J. Ghelani, Promethean Power Systems, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Solar Cooling Engineering as part of the SelfChill coalition	Locally produced modular cooling systems powered by solar (SelfChill Approach)	TRL 7, MRL 5	Cold storage; milk cooling; ice production	Off-grid solar	R-600a

Impact

- Innovative supply chain model: Local SelfChill partners in target countries purchase only the components they need from SelfChill Germany and source the remaining materials locally. They care for local assembly of cooling solutions, installation and maintenance. A SelfChill partner can adapt to the demand of its customers by offering customized systems that can be easily maintained.
- Improved food quality and food safety.
- Reduced food loss; increased income for farmers.
- Reduced reliance on fossil fuels and grid with solar power and thermal energy storage (ice).


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Source: S. Mettenleiter and V. Torres-Toledo, SelfChill, personal communication, August 2021

Developer	Project name	Technology Readiness Level (TRL) Manufacturing Readiness Level (MRL)	Target applications / cold chain elements	Energy source	Refrigerant
Thermo King/Trane Technolo-gies	Mercedes-Benz E-Sprinter using TK E-200 cooling system	TRL 9, MRL 10	Mobile refrigeration unit for last-mile deliveries	Fully electric, uses the Mercedes Sprinter auxiliary battery	Not specified

Impact

- Complete removal of fossil fuel-based emissions from unit.
- Further reduction of direct emissions by using next-generation low-GWP refrigerant.

Source: B. Tacka, Trane Technologies, personal communication, August 2021

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MINISTERO DELLA TRANSIZIONE ECOLOGICA