Net zero cold chains for food

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COOLING EFFICIENCY PROGRAM

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A discussion document on the case for philanthropic action

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The Kigali Cooling Efficiency Program (K-CEP) is a philanthropic collaboration launched in 2017 to support the Kigali Amendment to the Montreal Protocol and the transition to efficient, climate-friendly cooling solutions for all. K-CEP works in over 50 countries in support of ambitious action by governments, businesses, and civil society. K-CEP's program office, the Efficiency Cooling Office, is housed at the ClimateWorks Foundation in San Francisco.

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The Cool Coalition is a global network connecting over 100 partners from governments, the private sector, cities, international organizations, finance, academia and civil society to facilitate knowledge exchange, advocacy and joint action towards a rapid transition to efficient and climate-friendly cooling. Cool Coalition members collaborate on science, policy, finance and technology to support governments and industry meet their growing cooling demand through a comprehensive – "avoid-shift-improve-protect" approach.

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Executive summary

Challenges

- There are immense challenges with delivering food that is affordable, nutritious, and safe whilst providing optimal returns to farmers and others in the value chain as well as and minimising environmental and climate impacts.

- Cold chains are vital to help the food system deliver against those challenges, but their operations can have significant environmental impacts. For example, the food cold chain alone is responsible for a third of hydrofluorocarbon (HFC) emissions, or 1% of global greenhouse gas (GHG) emissions, and these HFC emissions are expected to increase significantly in proportion by 2050.

- GHG emissions from food cold chain infrastructure is already significant in developed countries. For example, food refrigeration contributes 2-4% of total GHG emissions in the UK.

- In developing countries, cold chain GHG emissions are projected to grow significantly. For example, studies in India highlight that GHG emissions from cold chains could more than double by 2027 without active intervention, highlighting the potential pace of growth of the sector and associated emissions.

- Despite these significant environmental impacts, cold chains also mitigate methane emissions by mitigating food loss and minimising wastage of resources used in the production of food.

- Cold chain expansion will likely continue by deploying conventional technologies in mid- and low-income countries, which risks locking-in GHG emissions from high global warming potential (GWP) refrigerants and inefficient energy use. This will make it harder and more expensive to retrofit energy efficiency, climate-friendly refrigerants, and renewable generation in the future.

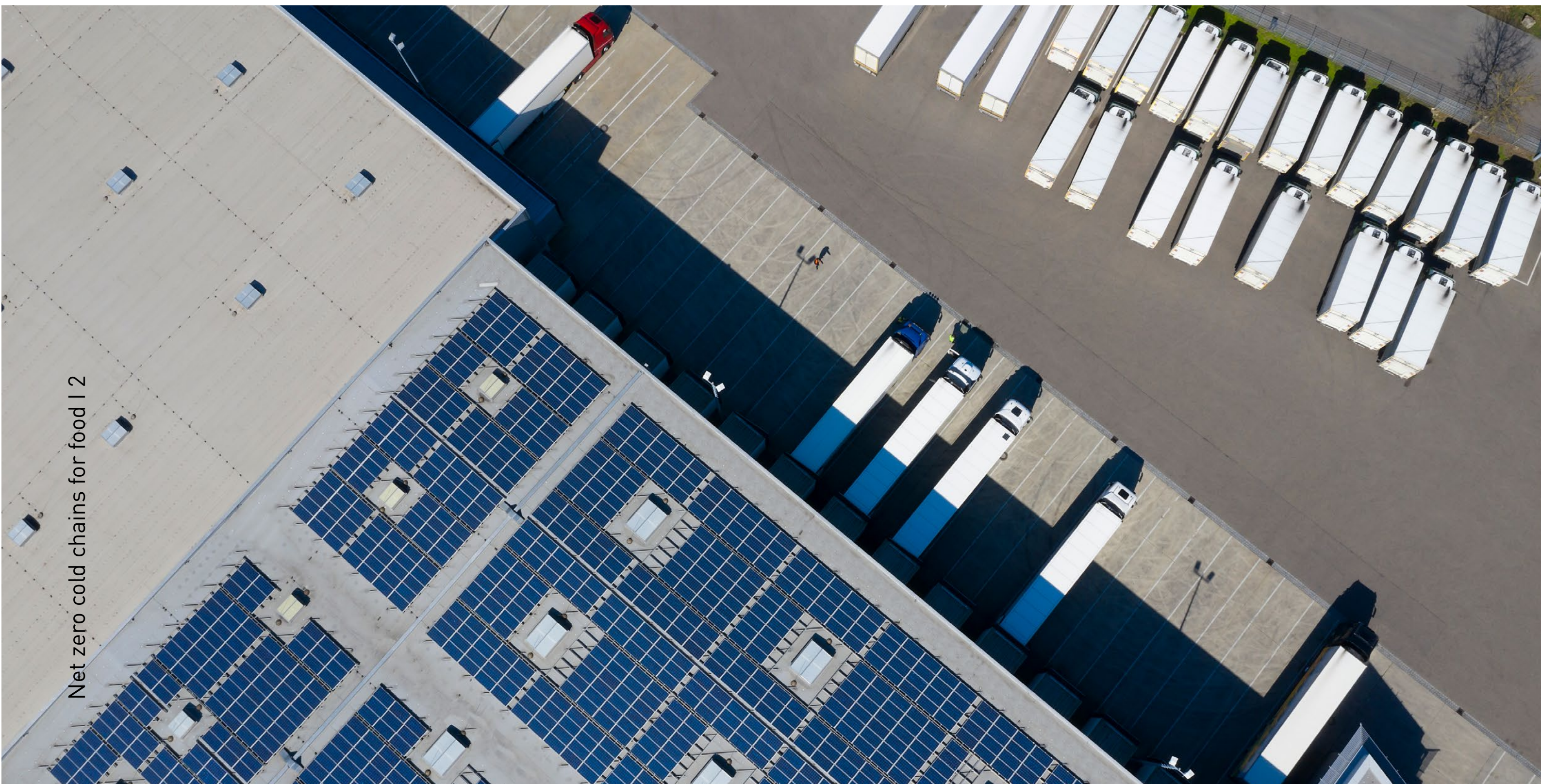
Solutions

- Cold chains integrate a logistics network of refrigerated assets that facilitate safe custody of goods under care. These assets, when designed with cooling technologies that use climate-friendly refrigerants and maximise the efficient use of low carbon energy, including via energy storage, can make cold chains compatible with net zero GHG emissions.

- There is an opportunity for many countries to leapfrog to net zero cold chain infrastructure and so significantly reduce the GHG emissions from such assets and the wider food system.

- The development of climate-friendly cold chains requires a system transition with multi-actor effort, low carbon infrastructure, access to reliable energy, and appropriate operating procedures, as well as supportive policy, regulation, and commercial incentives.

- Supporting actions now on net zero compatible cold chain solutions can help to 'bend the curve' on GHG emissions in countries that already have significant cold chain infrastructure, and help to avoid significant increases in GHG emissions in countries where cold chain deployment is expected to grow.



The case for philanthropic action

1. An integrated approach to net zero cold chains is unlikely to emerge organically as the effort and benefits are spread across many actors who lack capacity and incentives to coordinate strategically. Further, private sector actors may not consider developing or deploying clean technologies without support to overcome the cost burden of net zero cold chains for food.

2. This presents an opportunity for philanthropy to play a catalytic 'systems integrator' role in this complex sector, to reduce GHG emissions whilst delivering safer food to consumers and higher incomes to farmers. This can deliver climate change mitigation, food security, and poverty reduction objectives that are relevant to a wide range of philanthropic foundations and individuals.

3. A multi-pronged strategy covering: improved data, modelling, and awareness; end-to-end cold chain demonstrations that show how technology, business model, and finance solutions can unlock net zero cold chains; and support for advocacy on net zero cold chains can encourage key actors (policy, business, finance) to adopt more climate friendly practices, either bending the current cold chain pollution curve or leapfrogging to net zero. Working with national governments and other key stakeholders will help philanthropy to catalyse faster action at scale.

Report background

Context

Philanthropy focuses on the world's greatest challenges such as climate change, nutrition, health, and poverty reduction. Cold chains sit at the intersection of such challenges and yet very little has been done by philanthropy to understand and support advancements in the role that cold chains play in delivering social, economic, and environmental benefits.

The Kigali Cooling Efficiency Programme (K-CEP), through a focus on efficient, climate-friendly cooling, has also acknowledged the role of cold chains for climate and development benefits. However, many questions remain that need to be resolved to help philanthropy understand whether and, if so, how and where to act. In order to improve understanding of the case for philanthropic action, K-CEP commissioned this report from the Carbon Trust to summarise findings on the case for philanthropic action to support the development of net zero cold chains.

Method

This report was written on the back of desk research, a programme of expert interviews, and two online surveys – one aimed at existing K-CEP funders and the other to a broader audience with an interest in climate-friendly cooling. A total of nine phone interviews were conducted. Each interview consisted of 45-60 minute discussions with experts across the cold chain industry, academia, consultancies, non-governmental organisations, and cold chain development centres. A total of 34 survey participants responded and *Table 1* below details what sector these organisations represented.

In terms of geography, the majority of survey respondents either operated globally or in Asia, with one respondent from/operating in Latin America and the Caribbean.

Table 1: Survey respondent figure breakdown by sector

Sector	Number of respondents
Cold chain or storage industry	6
UN programme	4
Academia	4
Environmental or sustainable development NGO	6
Climate change consultants	4
Government	2
Philanthropic	5
Bank	3
TOTAL	34

Structure

This report is structured in three main sections: Section 1 gives an overview of cold chains for food and the baseline in terms of deployment, environmental impact, and growth trajectory; Section 2 introduces the building blocks of net zero cold chains, constituent parts, and key barriers; and Section 3 outlines opportunities to unlock greater efficiency and foster net zero cold chains, and provides recommendations for philanthropy.

Summaries of survey responses are presented throughout the report as *Survey Insight Boxes* aligned to the relevant sections. The report focuses primarily on cold chains for food although there are synergies with health/vaccine cold chains, which are also important. This focus was selected due to the larger scale of food cold chains and the assumed larger GHG emissions; the background of experts consulted; and to focus the analysis and final recommendations. Similarly, although innovations like indoor vertical farming, food coatings, and dehydration solutions have the potential to alter the scope and purpose of cold chains, as well as being important to consider when developing a view of the future in this sector, they are not within the scope of this report.

Perceptions on cold chains for healthcare were still gathered through surveys to highlight their significance and a similar study on the case for philanthropic action on cooling systems in healthcare centres would be useful. This report was drafted just before the Covid-19 pandemic outbreak and, whilst not covered in the report, the authors acknowledge the potential impact this crisis could have on the development of cold chains in the coming years, and the potential synergies between developing efficient, climate-friendly cold chains for health and food.

This work is written as a discussion document rather than as a prescriptive and conclusive report due to the nature of the cold chain sector, the disaggregated stages of efficient, climate-friendly cooling, and the intricacies of cold chain development. The report does, however, provide specific recommendations on how philanthropy can initiate action in the 'Recommendations for philanthropic action' section and develop a broader action plan for support.

1. Introduction to cold chains for food

Cold chains for food are crucial to modern societies: they serve populations with diversified food; reduce the amount of food lost; maintain food quality, value, and safety; and offer opportunities for enhancing farmers' livelihoods.

Cold chains are a temperature- and humidity-controlled system that integrates **a sequence of refrigerated preparatory, storage, and distribution activities** as illustrated in *Figure 2*. Certain production activities under refrigerated conditions can also be the source point of food cold chains. Cold chains exist for a variety of food and beverage commodities, most commonly perishable foods such as vegetables, seafood, meat, or dairy products. **These cold chains are complex to suit the food product under care, with different standard requirements or logistics equipment** and usually specific to a global or regional value chain. Policies driven by different departments such as health, agriculture, finance, and energy, are key enablers that shape cold chain development.

Figure 1: Ripening chambers for bananas in Tamil Nadu, India. Picture courtesy of Danfoss

Figure 2: Schematic overview of food cold chains

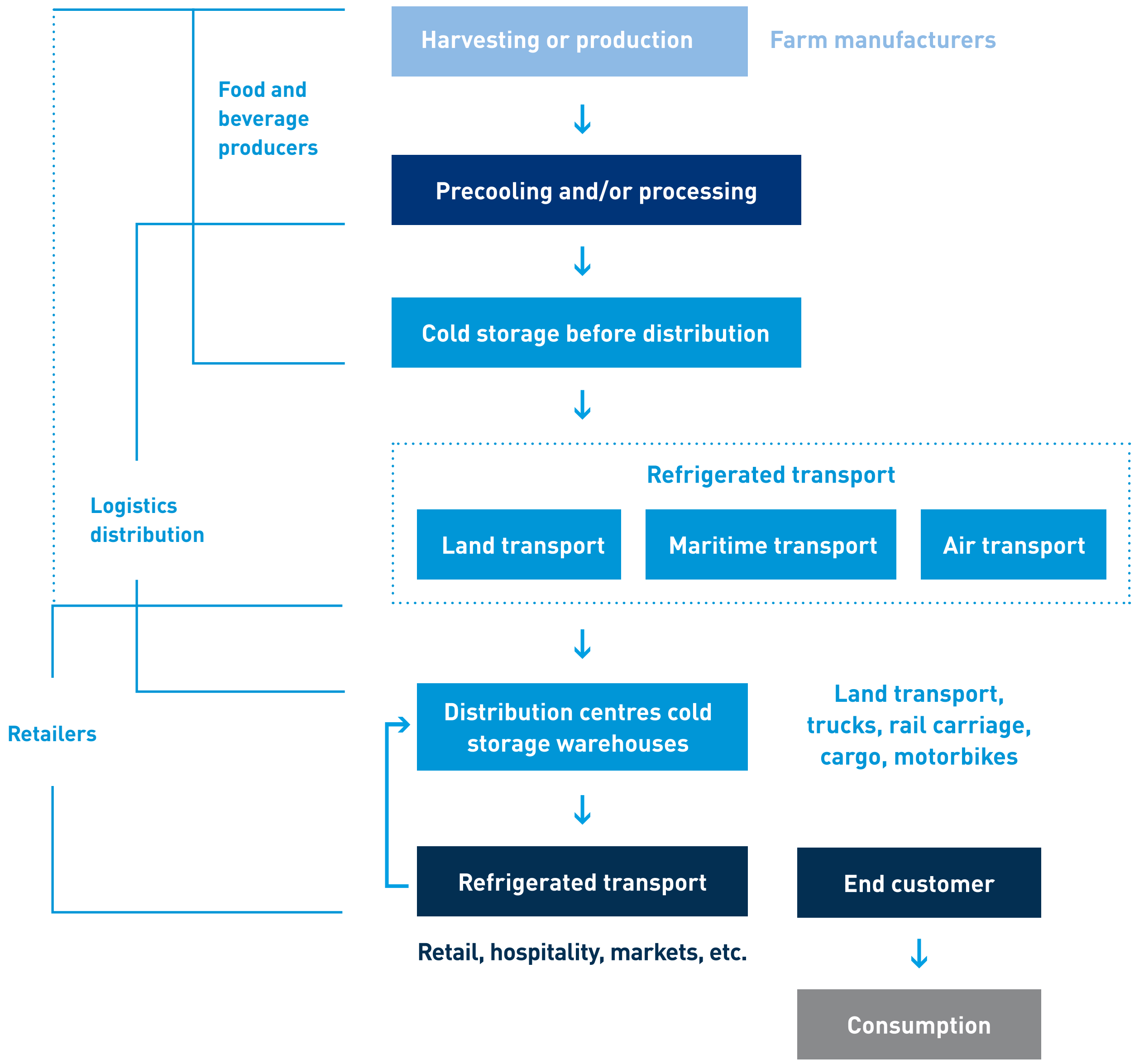
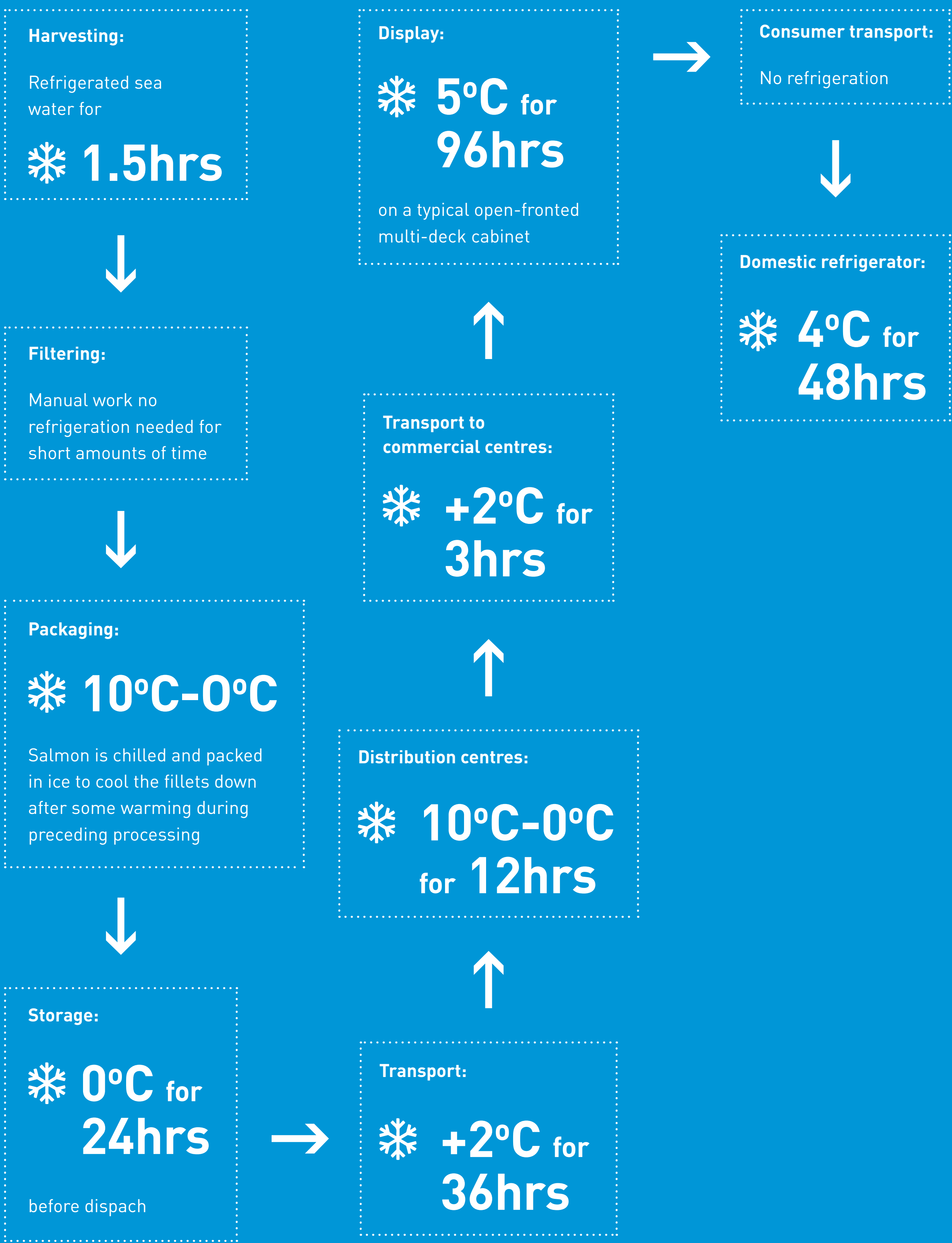


Figure 3: Overview of a salmon cold chain and temperature requirements[a]



[a] *An interpretation from the report: Hoang et al. Life cycle assessment of salmon chold chains: comparison. https://hal.archives-ouvertes.fr/hal-01555607/document (2015)*

1.1 Benefits of food cold chains

Reducing food loss and waste

Cold chains can play a major role in reducing food losses (at production, storage, processing, or distribution stages). In developing countries, 90% of food wastage is from food loss within the value chain, whilst 800 million people go hungry around the world[1]. There is a real gap in terms of perishable food being cooled, with **only 15% of all food requiring refrigeration being refrigerated due to energy shortfalls[2].** Well designed and developed cold chains can prevent these losses and reduce GHG emissions related to food waste.

Food loss and waste (FLW) is a major challenge in terms of straining natural resources, exacerbating malnutrition, and causing economic loss. It happens across the food chain and at different levels depending on a country's economy, food consumption habits, and cold chain infrastructure in place. It is estimated that FLW occupies a land area the size of Mexico and consumes 250km^3 of water per year (three times the volume of Lake Geneva). **The total carbon footprint of FLW, including land use change, is around 4.4 gigatons of carbon dioxide equivalent ($GtCO_2e$) per year[1].**

Cold chains can help eradicate the burden of food wastage estimated at almost $1 trillion per year. In sub-Saharan Africa, the cost of postharvest grain losses totals up to $4 billion per year. And in India, post-harvest losses of food grains accounts for 12 to 16 million metric tons every year, which could feed one-third of India's poor[3]. A greater focus on food security and the impacts of rising temperatures mean that efficient storage, temperature, and humidity silos are being increasingly used to help store grains. An example of such a facility is one installed by grainTECHNIK in the state of Bihar, which helps to keep the 3,500 tons of stored grain at a temperature of 16°C (from 37°C) and keeps the moisture content at 14%[b].

Improving farmers' incomes

Reducing losses through minimising post-harvest loss and waste, besides expanding access to markets, is essential to increase farmer's incomes. **In developing countries, food loss was estimated to reduce incomes by at least 15% for 470 million smallholders, farmers, and downstream value chain actors[1].**

Cold chains also offer opportunities for enabling greater trade by connecting different markets, which unlocks twin benefits. Firstly, consumers have access to a wider pool of products. Secondly, farmers can increase revenues by optimising production of high-value products that would otherwise incur high losses. A case study example of how cold chains can improve farmer revenues is detailed in *Case Study 2* in Section 2 of this report.

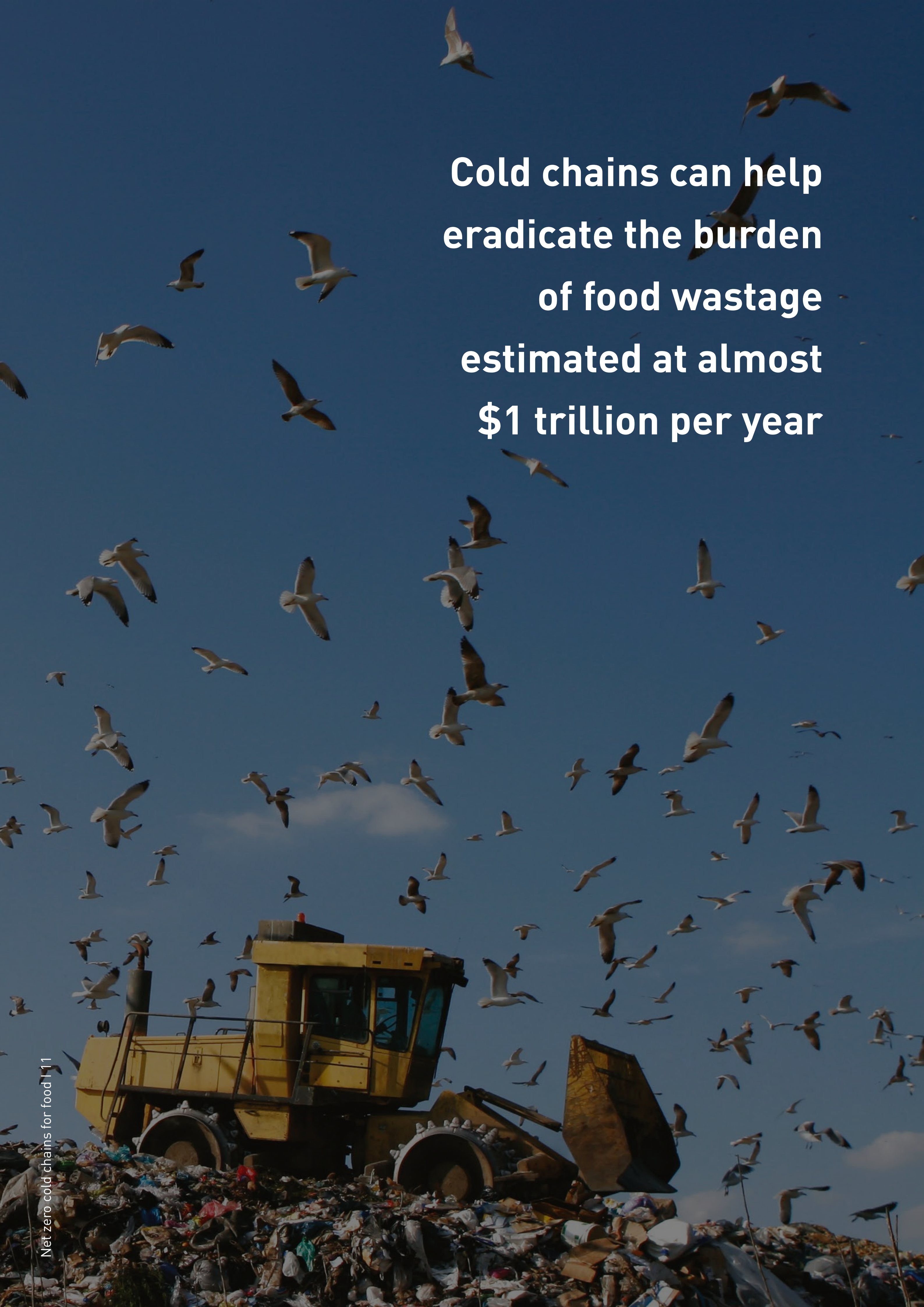
[b]More information on the facility can be found here - https://graintechnik.com/project/maize-storage/

Ensuring food safety and security

Cold chains transport food safely to demand and can extend the holding life of perishable products. They bring organisation in the food supply chain and by way of packaging practices and keeping proper storage conditions (i.e. temperature and humidity), products can reach the end consumer in a good condition and the risk of some foodborne diseases is reduced. This also increases access to perishable and nutritious produce. As an example, higher temperatures increase the proliferation of harmful bacteria living in different parts of a fish, which can cause serious food poisoning. While fish can be stored for ten days at 0°C, it can only last a few hours in the heat. However, cooling itself does not ensure supply and food security; it is cooling technologies along with associated logistics processes – the cold chain - that ensures the technology and the outcome is gainful.

More than **1.1 billion people are at risk of poverty and malnutrition.** In fact, more children die from malnutrition than from AIDS, malaria, and tuberculosis combined[4]. **Cold chains increase the supply of nutritious foods and can help reduce malnutrition and health, social, and economic consequences related to unhealthy diets.** The chain of activities that ensures safe custody of high-nutrition-value foods, allows the food supply chain to be robust and extends the reach of nutrition to underserved regions. Without such cold chain care, the food would perish before reaching distant demand areas.

Cold chains are also able to ensure food security by reducing food price inflation. With the introduction of refrigerated storage, food supply is buffered and overcomes seasonal shortfalls. This buffering mechanism dampens price fluctuations that typically puts vulnerable communities at high risk of poverty and hunger, due to 40-50% of incremental income being spent on food in low-income countries[4].


Cold chains can help eradicate the burden of food wastage estimated at almost $1 trillion per year

Survey Insight Box 1: Relative importance and impacts of efficient climate-friendly cold chains

Perceptions on efficient, climate-friendly cold chain impact

We asked survey participants to rank measures against their importance to tackle climate change. Efficient, climate-friendly cold chains deployment is considered critical but not the main priority.

Responses show **that addressing the need for efficient, climate-friendly cold chains is critical to avoid significant future climate impacts from traditional cold chains.** However, respondents consider phasing out of coal plants as the top priority to tackle climate change. While these questions were posed as discrete choices, in reality these actions need to be pursued in parallel to ensure system security, robustness, and cost effectiveness.

Rank	Measure
1	Phase out of coal plants
2	Increase renewable energy development
3	Improving agriculture and food systems
4	Making space cooling climate-friendly and efficient
5	Developing efficient climate-friendly cold chains
6	Increasing electric-mobility deployment
7	Making finance sustainable
8	Protecting and enhancing forests

Respondents: The respondent participation to rank all measures for the two questions above varied between 29 to 33.

We asked participants to rank the main impact of efficient, climate-friendly cold chains. The main impact is perceived to be on improving food security and nutrition.

While efficient, climate-friendly cold chains have significant environmental and climate benefits, respondents predominantly see it as **delivering impacts for food security and nutrition, farm livelihood, and saving lives.** This, together with the ranking table above, highlights the weak association that exists presently between greening cold chains and climate change mitigation. **This can be explained by the lack of sound data on the environmental and climate footprint of cold chains and the fact that it is a forward-looking problem.** Therefore, there is a lack of understanding on the climate implications of these systems. Further studies are needed to assess and make the climate implications explicit.

Rank	Measure
1	Improving food security and nutrition
2	Improving livelihoods of farmers and food sector workers
3	Saving lives
4	Mitigating greenhouse gas emissions
5	Climate adaptation

1.2 Current status of cold chains

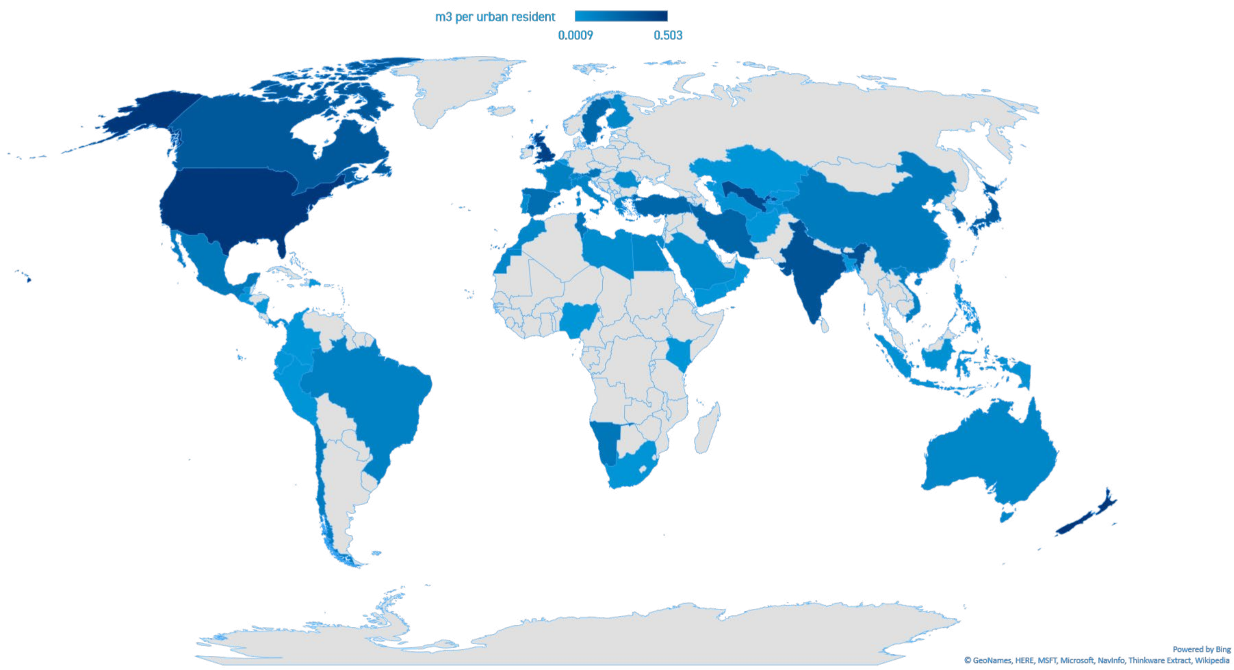
Cold chains play a key role in our societies and are expected to grow. However, the complexity of cold chain infrastructure and diverse stakeholders at play complicates the data availability and market traceability of the sector as a whole.

The Global Cold Chain Alliance's (GCCA) latest report[c] on global refrigerated warehouse capacity estimates a total capacity of 616 million cubic meters in 2018 with India, the United States and China having the largest country markets with about 60% of the global total of refrigerated space[5]. However, refrigerated warehouse space is reported to be unevenly distributed based on the alliance's index of market penetration. Urban populations are used in this benchmark based on the assumption that urban centres are expected to concentrate most of the middle-class income population.

On average, there are approximately 0.2 cubic meters of refrigerated warehousing space per urban resident globally. The size of refrigerated warehouses varies between 15,000 to 100,000 cubic meters per facility, with the largest capacities located in developed economies.

Findings show that many of the higher-income countries have a higher presence of refrigerated warehousing capacity relative to their urban population. The highest market index levels were in New Zealand, the United States and Great Britain as shown in *Figure 4.* There are however major gaps in terms of data availability and accuracy on cold chain deployment particularly for lower and middle income countries.

Figure 4: Cold storage market development index map. Data source GCCA*, 2018



[c]The Global Cold Chain Alliance is an association representing 1,300 cold chain members across 85 countries and serves as a voice for the cold chain industry. Members represent Public Refrigerated Warehouse companies that reported against country's cold store capacity to the alliance. The type of data collected varies on a country basis and may be warehouses that store food for more than a month only or may just be for a specific product and food type.

There is a large variance in cold chain penetration based on each country's income group. This effect can be seen in *Figure 6* particularly in high income countries where there is an increase of cold storage capacity. Some of the smaller countries in terms of population that have a large cold chain capacity such as New Zealand are large food product exporting countries. 45% of all exports from New Zealand are food products or by-products and 60% of these are exported in a refrigerated state[6].

Figure 5: Cold storage market development index graph. Data source GCCA, 2018

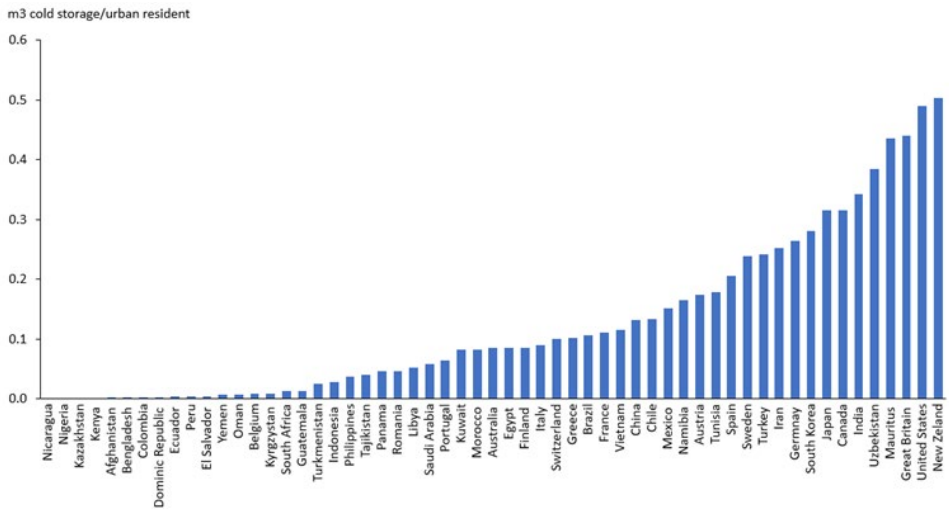
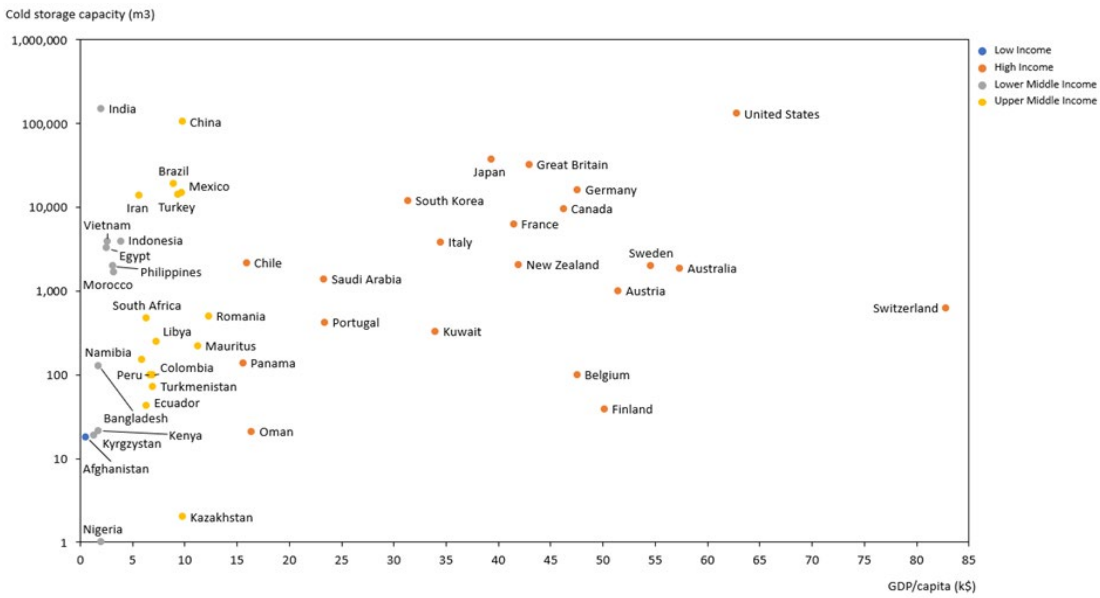


Figure 6: Cold storage capacity 2018 (log scale) vs GDP/capita. Data source for cold storage capacity (GCCA) and data for income classification from World Bank, 2019 (Carbon Trust analysis).



The greatest variation can be seen in the lower middle-income countries with India at the top and Nigeria at the bottom in terms of cold chain capacity. Generally, as countries grow economically, their ability to deploy cold chains increases as a function of its: agri-food sector growth and trading patterns; purchasing power of consumers; and development of modern retail infrastructure.

While data on cold storage capacity provide a useful indication of the status of cold chain development globally, it is important to note that there are other components of the cold chain which is not covered in such data. Additionally, the type and extent of cold-chain infrastructure depends on food preferences, spread and scope of food production and the time-distance requirements posed on the cold-chains. Caution must be applied when viewing these figures in isolation and when comparing them across countries/regions that have different contexts of the factors described above.

India is an outlier as a lower middle-income country with a high cold storage capacity. India has quickly been able to deploy cold storage as a consequence of economic growth, development of its agri-food sector (including processing), and significant and focussed government support. Some of the highlights of the government support include:[d]

- The Indian Government offered lower interest loans for the setup of cold chains through a $650m[7] loan facility made available to the National Bank of Agriculture and Rural Development between 2012-2015;

- Up to 50% subsidy support of admissible costs for cold chain infrastructure development to offset credit burden from commercial banks;

- Priority Sector Lending status for credit under Reserve Bank of India policies;

- Capital grant scheme for supporting set up of "mega food parks" for food processing linked cold chain development[8];

- Full exemption of GST on all services related to preconditioning (sorting, grading, packaging, precooling), loading unloading transporting and storage of agricultural produce;

- 100% Foreign Direct Investment (FDI) via automatic route for investment in cold chain.

Today, India is the largest milk producer and second largest fruit and vegetables producer globally.[9] In the past decade, the economic growth of the country has boosted demand for food products and, as a result, increased retail outputs and spending. Between 2012 and 2017, India's compound annual growth rate in consumer spending on grocery retail reached 12.5%. The government initiative to support farmers and respond to an increased demand acted as a key enabler for cold chain development. This example showcases opportunities for rapid cold chain deployment in similar lower-middle income countries with high economic growth trajectories and a sizeable agri-food sector.

[d]*Support to cold chains and allied components*

The demand for cold chains for food are anticipated to expand dramatically

1.3 Environmental impact of conventional cold chains

The demand for cold chains for food are anticipated to expand dramatically as the global population grows, developing countries become more prosperous, and urbanisation increases. Food will have to travel longer distances from production sites. This future deployment of cold chains is likely to bring high environmental costs if they are developed with conventional technologies.

Conventional cold chains for food are energy intensive, and use high-GWP refrigerants and fossil-fuel intensive transport fleets to feed populations across the world. Refrigeration is an energy-intensive process that accounts for 15% of worldwide electricity production, and the leakage of the refrigerants used are responsible for 15-20% of the global warming effect of refrigeration[10]. Estimating the exact impact of cold chains on the environment is a challenging exercise as the type of cold chain logistics varies from one region to another and data on energy consumption or emissions of different sections of the cold chain is inconsistent. The limited data available suggests that food cold chains account for 1% of CO_2 emissions globally[11]. In the UK, it is estimated that food refrigeration is responsible for 2-4% of the country's total GHG emissions[10]. Significant GHG emissions are caused by fuel consumption of mobile refrigeration units, and there are an estimated 4 million food transport vehicles in the world. This number is predicted to increase by 2.5% by 2030. A brief summary of the different sources of emissions in cold chains and an indication of their scale is outlined in *Table 2* below.

Table 2: Overview of sources and amount of emissions from different parts of a cold chain

Food cold chains processes	Overview of emission sources	Amount of emissions
Post-harvest cooling (including cleaning, packaging, etc.)	• Refrigeration is an energy intensive technology. Depending on the type of food and efficiency of operations, refrigeration can account for 60-70% of electricity used in the facility[12]. • The energy load also depends on the commodity and the cooling system (e.g. precooling, blast freezing, chilling for fresh produce, meats, and milk).	• There are no accurate estimates of GHG emissions from the electricity use of post-harvest cooling globally due to the divergence in energy use across different countries. • The range of precooling, especially for fruits and vegetables, is also defined by the regional selling cycle of these food type.

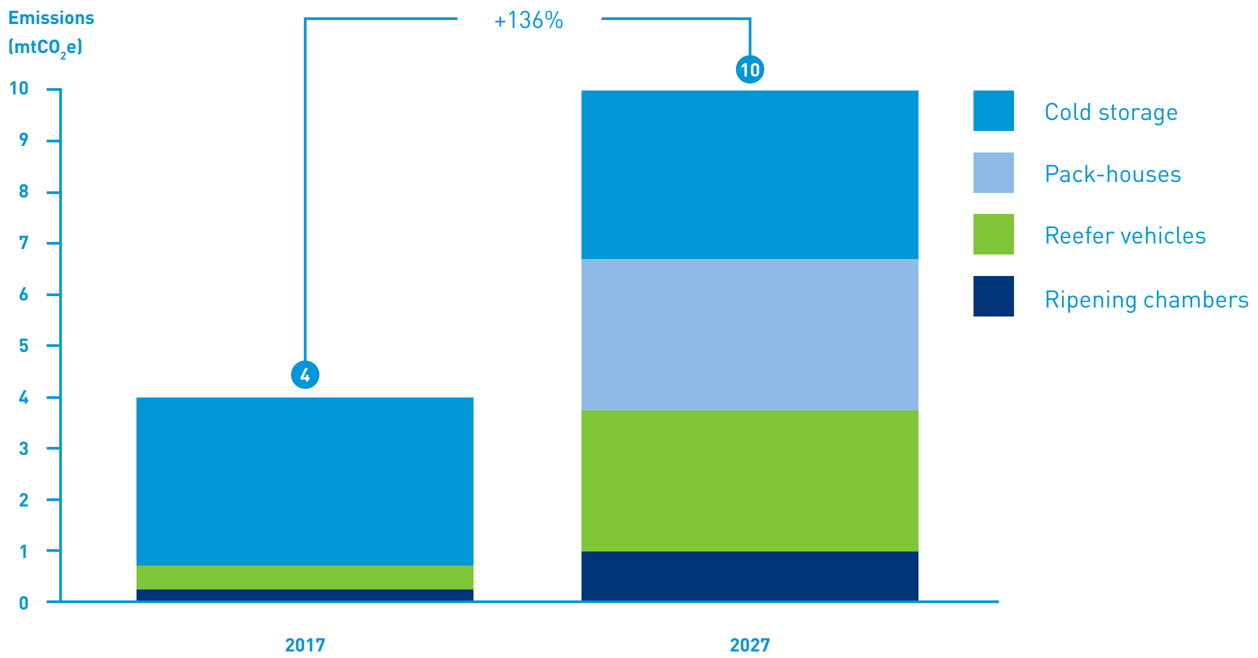
Food cold chains processes	Overview of emission sources	Amount of emissions
Transport (land, maritime, and air)	• Depending on the type of refrigerated truck and the temperature maintained, it can use approximately 20 litres of diesel/ hour of travel. • The refrigeration unit uses approximately 8% of total fuel consumption of the truck when in use[13]. • Refrigerants such as R134a are used across most forms of refrigerated transport. These refrigerants leak at different rates (30-80 grams (g)/year) owing to pressure, the condition of the system, and vehicle age[14].	• CO_2 emissions from refrigerated medium, large, and 32- to 38-ton vehicle varies between 51g CO_2/ pallet/kilometre (km) and 115g CO_2/pallet/km depending on temperature conditions.[2] • Refrigerants could raise CO_2 emissions from food vehicle transport systems by up to 40%.[2] A large class vehicle with a refrigerant charge of 6 kilograms (kg) and an annual leakage rate of 20% is estimated to produce 5.3g CO_2/ pallet/km.[15] • Studies carried out in New Zealand on the energy-use and emissions from refrigerated maritime transport show that around 280gigawatt hours (GWh) of energy was required to maintain the refrigerated state of the products imported and exported in 2007, emitting around 190kilotonnes of CO_2.[6]
Mid-chain storage (including short& long-term storage and warm-up for ripening)	• There is large observed variance in energy consumption within cold stores. It can vary from 20kilowatt hours (kWh)/m3/year to 120kWh/ m3/year with higher values for frozen and mixed stores.[16] • The energy load also depends on whether the produce handled is precooled. Breaches in such practices detracts from the efficacy and efficiency of the cold store.	• HFC emissions are growing at a rate of 8-15% per year and are the fastest growing climate pollutants in many countries, including the US, Australia, and India, all of which are countries with high cold store capacity.[17] • The injection of refrigerants in cooling systems result in high risk of refrigerant leakages with high GWP.
Retail	• Supermarket refrigeration ranges between 1% and 3% of electricity consumption in developed economies.[18] Retail refrigerated shelves vary in design, layout, and efficiency. Refrigeration systems can use up to 600kWh/m3/year depending on the type of system.[19] • Up to 890kg of refrigerant charge is required for retail cabinets.[20]	• Cooling sectors currently account for 86% of the GWP weighted share of global HFC consumption. The cumulative direct emissions from these sectors could reach 90GtCO_2e for which commercial refrigeration would represent 23GtCO_2e by 2050.[21]

Sector-wide emissions from cold chains in India

Recent studies from India have estimated the energy use and carbon emissions associated with its cold chain, including cold stores, pack houses, ripening chambers, and reefer vehicles. **The total energy use in 2017 was estimated to be 5,233GWh, which was responsible for 4.1 million tons CO_2e of GHG emissions**. In terms of the sources of these emissions, 90% came from cold stores, 8% from reefer vehicles, 2% from ripening chambers, and about 0.5% came from pack houses).[22]

Emissions figures will likely change in the future as more focus is put on developing pack houses and reefer trucks in an effort to double farmers' income, which is being driven by the focus of the Government of India. This effect can be seen to some extent in *Figure 7* below, where the emissions from pack houses and reefer trucks will see a sharper increase compared to cold storage, and the total emissions are forecasted to grow by 136% over the next decade.

Figure 7: Growth in Indian cold chain emissions 2017-2027 by component. Data source Kumar et al. 2018[23]



Trade-off between reduced GHG emissions from reduced food loss and increased GHG emissions from the introduction of conventional cold chains

As countries transition to more affluent and developed economies, food delivery systems and infrastructure are also expected to evolve. This development will result in improved custody and connectivity that reduces post-harvest food loss and food loss related emissions. However, the emissions from operating cold chains are also expected to increase. The extent to which they will increase will depend on the type of energy used, the efficiency of use, and the refrigerants used in the cooling systems. This is a critical aspect for cold chain development, and if countries rapidly deploy new cold chains in the conventional fashion, following past trajectories of high-income countries, this could potentially increase the net GHG emissions of cold chains, even after accounting for savings from reduced food loss.

Research is nascent in terms of quantitative studies that analyse the extent of this trade off and the different drivers given the complexities of modelling cold chain development and changing dietary patterns. This section presents examples of recent studies to highlight the scenarios of cold chain development and consequence for net GHG emissions.

A study from Michigan University[24] modelled sub-Saharan Africa food systems – which currently have the highest upstream food loss rates due to a lack of cold chain – as a baseline to examine the potential cold chain deployment:

- The key parameters included loss rates (percentage of food loss at food supply chain stages), demand for food (food consumption per capita), agricultural emissions factors, and cold chain emissions factors.

- The study assessed emissions for seven food types and investigated the implications of switching to a North American or European diet.

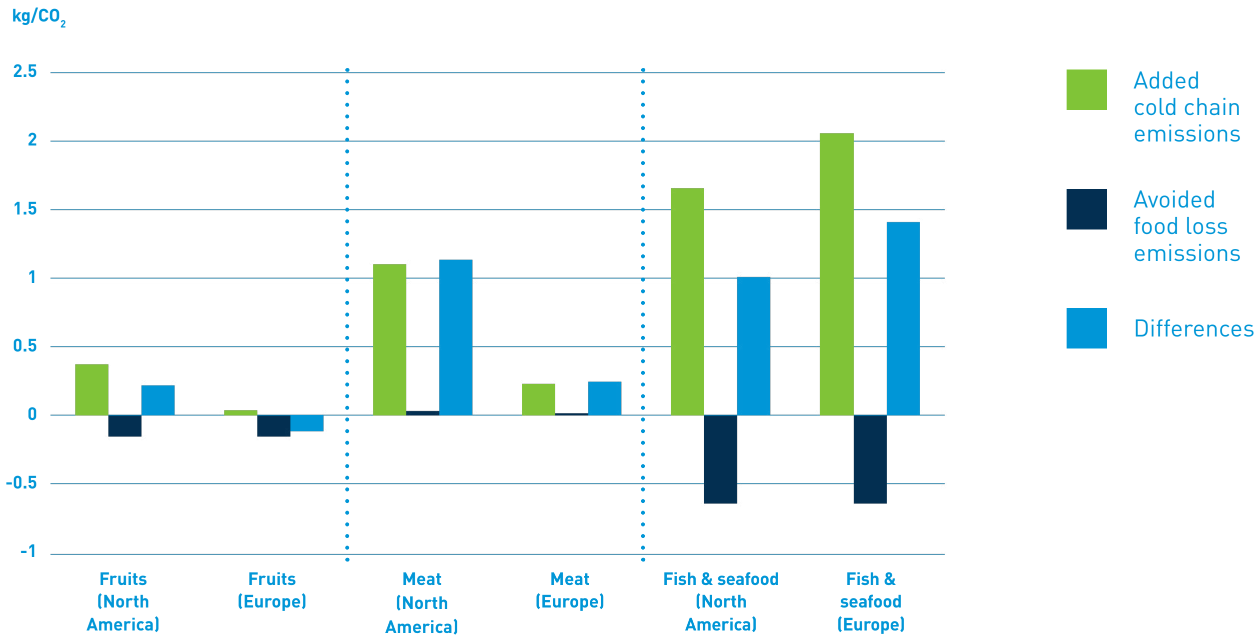
- When estimating the upstream emissions from introducing cold chains, the study finds that emissions increase based on the use of existing technology. This assumes that wider systemic effects such as changes and efficiencies in agricultural production or dietary shifts, are not included in the estimation. Results show that introducing refrigeration to sub-Saharan Africa would increase net food related GHG emissions by 10% from the baseline in a North American scenario, and 2% in the European scenario, despite reducing postharvest food loss quantities by 23%.

- However, when considering shifts in dietary patterns and indirect impacts of cold chains in agricultural production, upstream emissions increase or decrease depending on the scenario. The study finds that under the North American cold chain model, upstream emissions increase by 10%, while under the European scenario these decrease by 15%. This is mainly explained by food consumption characteristics, with North America consuming greater amounts of meat.

Data on FLW, as well as from cold chains in the developing world, is limited and uncertain. Further studies with refined data would help better understand this correlation and the implications of conventional cold chain development. Sub-Saharan Africa is not uniform by country, and regional disaggregated data would improve the accuracy of this study.

While the Michigan study took a much wider look at the impact of cold chains through modelling, a study conducted in India analysed this from a specific product and applied perspective. This study piloted two logistic systems – one with open truck transportation without cold storage or pre-cooling, and another with reefer trucks and cold storage with pre-cooling. The study took a specific product approach and focussed on Kinnow, which is a popular citrus fruit in India. Data on costs across the different points of the suppy chain, revenues and profit for the different actors involved, and CO_2 emissions were calculated to analyse the impact of the cold chain interventions. The results from this study on the carbon emissions concluded that the interventions with the cold chains saved overall emissions with just over 16% reductions per tonne of Kinnow sold – after accounting for emissions from refrigerant leakage, diesel, and electricity use. Such studies illustrate the value of focussed demonstration projects to better understand costs and benefits (monetary and climate) of cold chains.[25]

Figure 8: Comparison of median emissions added from cold chain introduction and emissions associated with avoided food losses for three food types based on American and European cold chain deployment scenarios. Data source, Heard & Miller 2019[24]



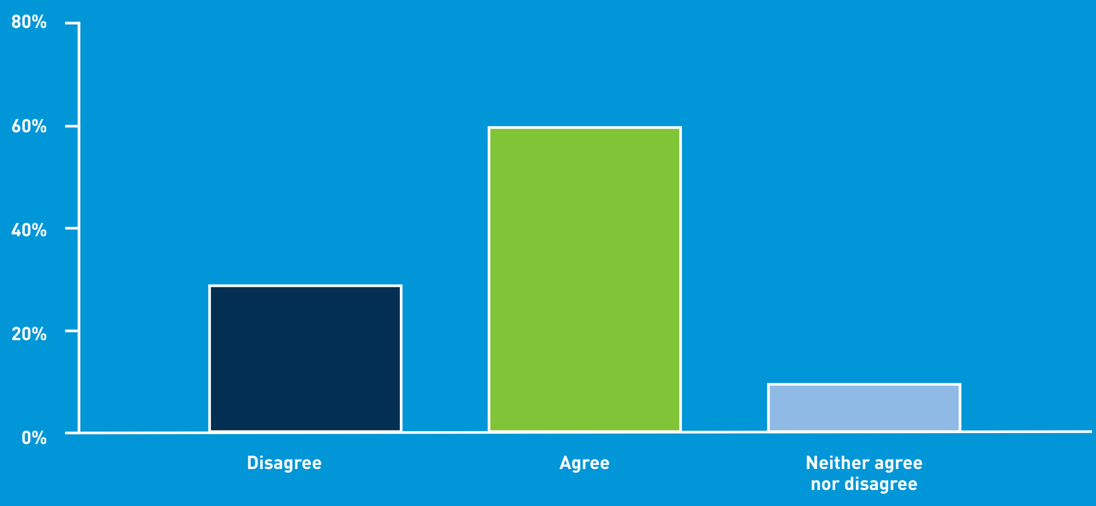
Survey Insight Box 2: Respondents' perception of potential trade-offs of cold chain emissions

Perception on the potential trade-off of cold chains

Do you agree or disagree with 'emissions from conventional cold chains could offset any savings generated from the food wastage reduced?'

Further research is needed to provide greater certainty on the exact emissions impact and potential offset on the reduction in food loss related emissions of cold chains. From interviews and survey responses, participants intuitively agreed with this concept, but a couple of stakeholders debated this assumption as the benefits of cold chains, even conventional, are much wider than negative environmental impacts based on the limitations with available data.

Respondents: 33 survey participants answered this question.

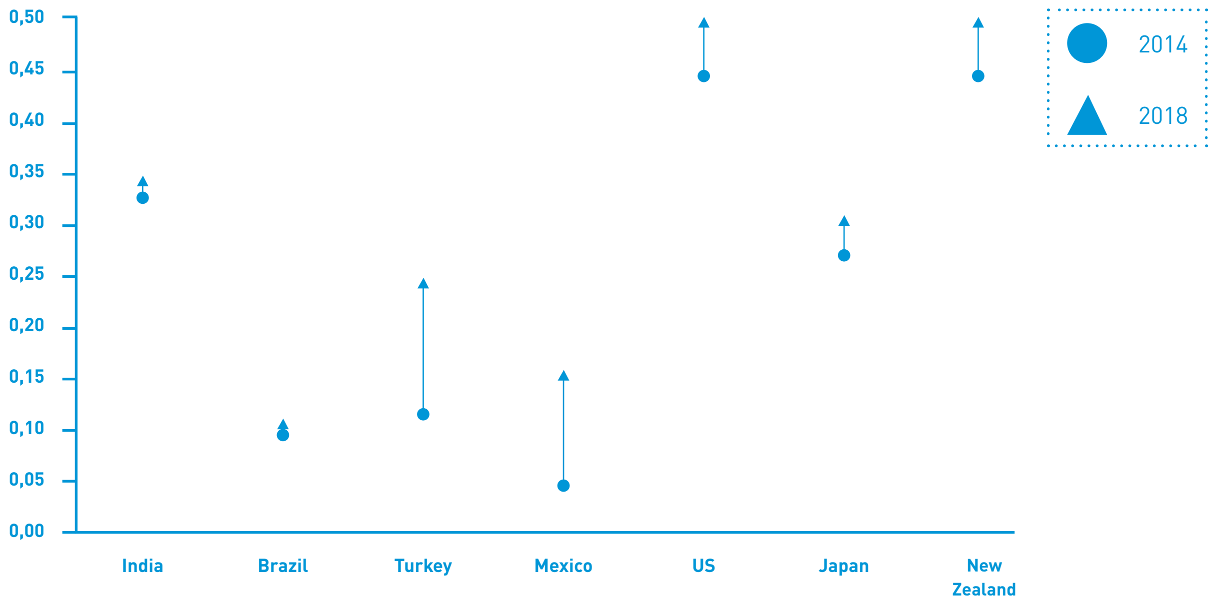


1.4 Cold chains for food poised for growth due to an expected increase in demand

Cold chain deployment and growth depends on the stage of economic development, nature of the agri-food sector, and wider preferences for food. Historically, in developed countries such as the United States, food safety regulations have played a critical role in developing cold chains as temperature requirements to prevent foodborne diseases were imposed. In these examples, the sector is characterised by private sector enterprises focusing on technology development. In other countries, it has been driven by a multitude of factors including a focus on improving farm income, market development for a food or horticultural product, and greater focus on loss reduction in the supply chains.

With the global population forecast to reach nine billion by 2050, food demand is set to grow by 50% during that time.[26] The global middle class is predicted to increase from about two billion people today to almost five billion in 2030, with almost all this growth coming from people living in developing countries, accelerating the shift towards urban living and more calorie-intensive diets.[27] As an example, the Food and Agriculture Organization (FAO) has reported that the share of meat and dairy products in people's diets has increased with economic growth, while the share of cereals has diminished.

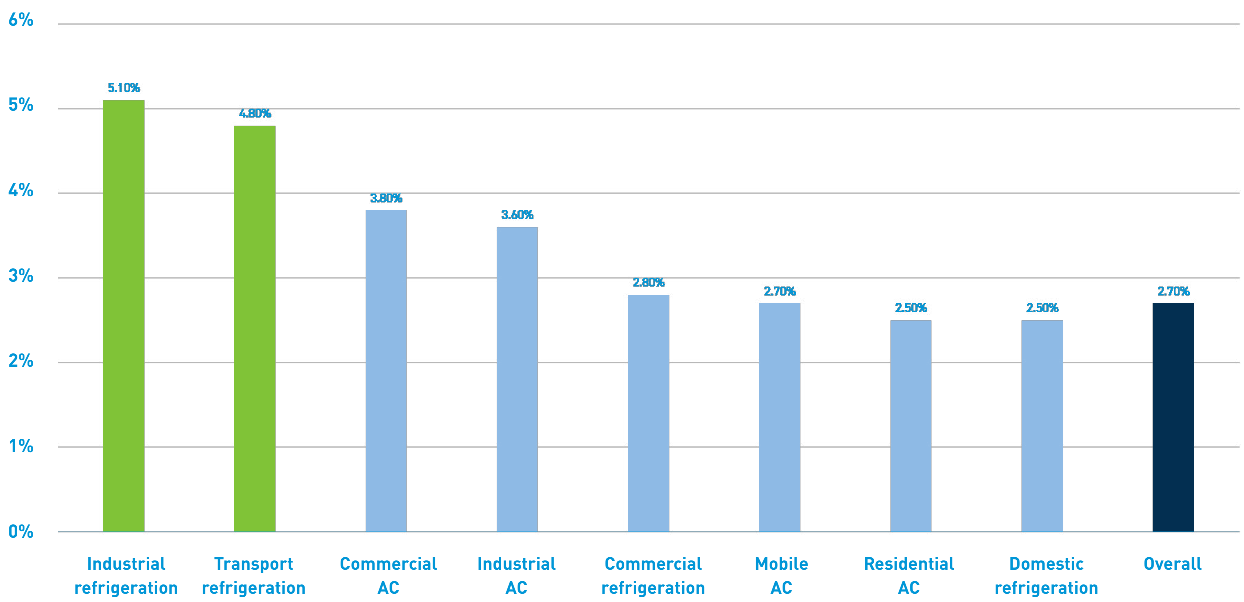
Figure 9: Cold storage market index growth between 2014-2018.
Data source GCCA, 2018 and Carbon Trust analysis



The type of food demanded is also likely to change going forward. There is a well-researched trend of changing dietary patterns with increasing income levels. For example, studies on changing dietary patterns in India show the **intake of dairy, fruits, and vegetables is set to rise rapidly to the mid-2020s, with smaller increases or decreases in the consumption of rice, wheat, and pulses.**[28] Dietary patterns also depend on cultural characteristics. The fact that India's food consumption is likely to increase with a vegetable-based diet as opposed to meat is reflective of the predominantly Hindu tradition across the country.

With the vast and currently unmet need for cold chains, combined with an expected increase in demand for perishable foods, **cold chains are expected to expand as a response. Consequently, cold chains are estimated to be a key contributor of industrial and transport refrigeration growth.** The Economist Intelligence Unit led a study on the expected growth of cooling based on cooling sales forecast. **Their estimates show that industrial and transport refrigeration are the fastest growth areas across the cooling sector, with an annual rate of 5.1% and 4.8% respectively between 2018 and 2030** as shown below in *Figure 10*. This represents a higher growth rate than air conditioning or commercial and domestic refrigeration.

Figure 10: Cooling sales: average annual growth rates 2018-2020 – The Economist Intelligence Unit, 2019[29]



Estimates show that industrial and transport refrigeration are fastest growth areas across the cooling sector with an annual rate or 5.1% and 4.8% respectively between 2018 and 2030

As economies grow, food waste and loss are expected to grow. A 1.9% annual increase between 2015 and 2030 would lead to a total of **2.1 billion tons of wastage in 2030 worth $1.5 trillion.**[30] Cold chains have a critical role to play as the lack of cold chains affects the rate of perishable food loss. Estimates show that 9% and 23% of perishable foods are lost in developed and developing countries respectively, due to the absence of cold chains. The extent and type of cold chain development to 2050 will thus impact the total food demand over that time.

More affluent populations and increasing competition between a small range of food suppliers on aesthetic standards has the effect of increasing and exacerbating food wastage. Globally, consumers were wasting as much as 727 kilocalories (kCal)/day/capita in 2011, rising from 526 kCal/day/capita in 2005. If growing economies follow the same growth paths as developed regions, similar food waste patterns are likely to emerge.[31]

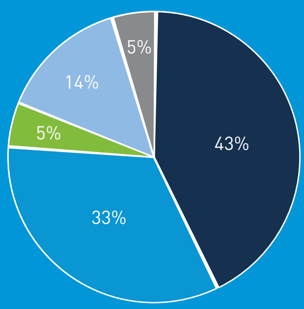
Climate change pressures will also strain future resources and increase the need for cold chains. With rising temperatures, the frequency and intensity of droughts or flooding is impacting food cycles, deteriorating arable land, and reducing water availability. Food prices are anticipated to rise and food supply to become more volatile. Oxfam simulations estimated that another US drought in 2030 could raise the price of maize by as much as 140% over and above the average price of food in 2030. In Africa, drought and flooding could increase the cost of a 25kg bag of corn meal from around $18 to $40. Extensive flooding across Southeast Asia could see the world market price of rice increase by 22%.[32]

Survey Insight Box 3: Insights on cold chain growth trajectory and drivers

Perception on cold chains growth trajectory and drivers

Cold chains are expected to grow rapidly, primarily with the use of conventional technologies.

Similar to findings in the literature, respondents are expecting to see a significant growth in cold chain development aligned with forecast drivers of growth such as increases in population, income, and urbanisation. 43% of respondents expect the development of cold chains to happen rapidly and with conventional technologies. However, a significant share of respondents also expected efficient, climate-friendly cold chains to develop rapidly.



- Cold chains will grow rapidly and primarily from conventional technology
- Cold chains will grow rapidly and primarily from efficient, climate-related technologies
- Cold chains will grow slowly and primarily from efficient, climate-friendly technologies
- Cold chains will grow slowly and primarily from conventional technology
- No material growth of cold chains is anticipated in that time period

Respondents: 21 participants shared their opinion on the growth trajectory of cold chains.

We asked participants to rank the main drivers contributing to the development of cold chains

We acknowledge that there are multiple cold chain drivers, usually working together, but we aimed to understand what was perceived as the main driver for cold chain development. Respondents considered the increased demand for perishable food as the main one. This suggests a market-led development of cold chains driven by changing consumer food needs. Conversely, the second highest contributor suggests that cold chains are driven by government regulations to meet food safety standards. This potentially highlights the different trajectories of cold chain development in developing countries compared to developed ones.

Rank	Driver of cold chain development
1	Demand for perishable food
2	Food safety and regulations
3	Addressing vaccination needs globally
4	Food waste reduction / cost savings by businesses
5	Well-developed transport and logistics industry

Respondents: The level of participation to rank all measures for the two questions above varied between 31 and 34.

2. Building blocks of net zero cold chains

A net zero cold chain can be defined as a safe, monitored, and integrated refrigerated network designed with cooling technologies that uses environmentally-friendly refrigerants and maximises the efficient use of low carbon energy.[e]

In the context of the food sector, it enhances economic wealth, cash flow, and security for farmers, and improves food quality and safety with minimum environmental impact. Food systems are becoming more interconnected and trending more towards fresh and frozen foods. Cold chains are the only known logistics mechanism to manage this.

A net zero cold chain requires an ecosystem of policy, regulation, wider logistics, and energy system development, as well as efficient producer and consumer behaviours to deliver sustainable economic, environmental, and social outcomes. When breaking it down in sections of the conventional cold chain, a sustainable version could include the following elements:[f]

Table 3: Net zero cold chain measures

Cold chain segment	Net zero measures
Policy level	• Sectoral government departments develop a national cooling plan, align to a vision, and join efforts to develop an enabling environment for the development of net zero cold chains
Post harvest precooling, production or manufacturing *Precooler, cold room or cold store*	• Passive cooling • Renewable energy use • Low-GWP and natural refrigerants • Energy efficiency • Storage and flexible demand • Data driven temperature monitoring and optimisation • Innovative business models (e.g. 'cooling as a service')
Refrigerated Transport • *Land, maritime, or air transport*	• Electric Vehicles • Low-GWP and natural refrigerants • Energy Efficiency • Use of green hydrogen and ammonia for ships • Thermal storage • Data driven temperature monitoring and optimisation

[e] *For more details on what climate-friendly and energy efficient cold chains could look like, further definitions specific to refrigerators can be found in the following U4E report: https://united4efficiency.org/wp-content/uploads/2019/11/U4E_Refrigerators_Model-Regulation_20191029.pdf*

[f] *These solutions are in different stages of technical maturity and commercial availability*

Distribution centres Cold storage warehouses or cold rooms	• Passive cooling • Renewable energy use • Low-GWP and natural refrigerants • Energy efficiency • Storage and flexible demand • Data driven temperature monitoring and optimisation • Innovative business models (e.g. 'cooling as a service')
Retail – end consumer Retail, hospitability markets, health centres, etc.	• Low-GWP and natural refrigerants • Energy efficiency • Storage and flexible demand • Data driven temperature monitoring and optimisation • Innovative business models • Renewable energy use

Survey Insight Box 4: Perceptions on efficient, climate-friendly cold chains

Survey responses on defining an efficient climate-friendly cold chain

"Cold chain requires a logistics platform that connects demand and supply and allows companies and other cold chain entities to offer services on the cold chain, e.g. think 'Uber of cold chain'."

"Climate-friendly also needs to imply minimising the loss of food - could be that it's better environmentally to power a cold chain with diesel which has zero percent food loss than one that runs on solar but where 50% of food is lost."

"It would be good to directly include the "passive" equivalent measures (i.e. non-mechanical) that are critical to ensuring unbroken cold chains, which includes removing the need for refrigeration (insulation/natural cooling/removing items that do not need to be refrigerated), reducing the amount of refrigeration needed (location of the refrigeration) and changing supply chains to minimize the length of the cold chain."

"An efficient, climate-friendly cold chain in an integrated refrigerated network that uses energy-efficient technologies and environmentally-friendly refrigerants without compromising temperature and hygiene standards or meaningfully increasing direct costs."

Two examples of how net zero cold chains are developing around the world are presented below. The first example highlights how advances in storage technology can make cold warehouses more energy efficient and flexible to enable greater use of renewables. The second highlights the value of taking a strategic approach for cold chain development in terms of environmental and development impact.

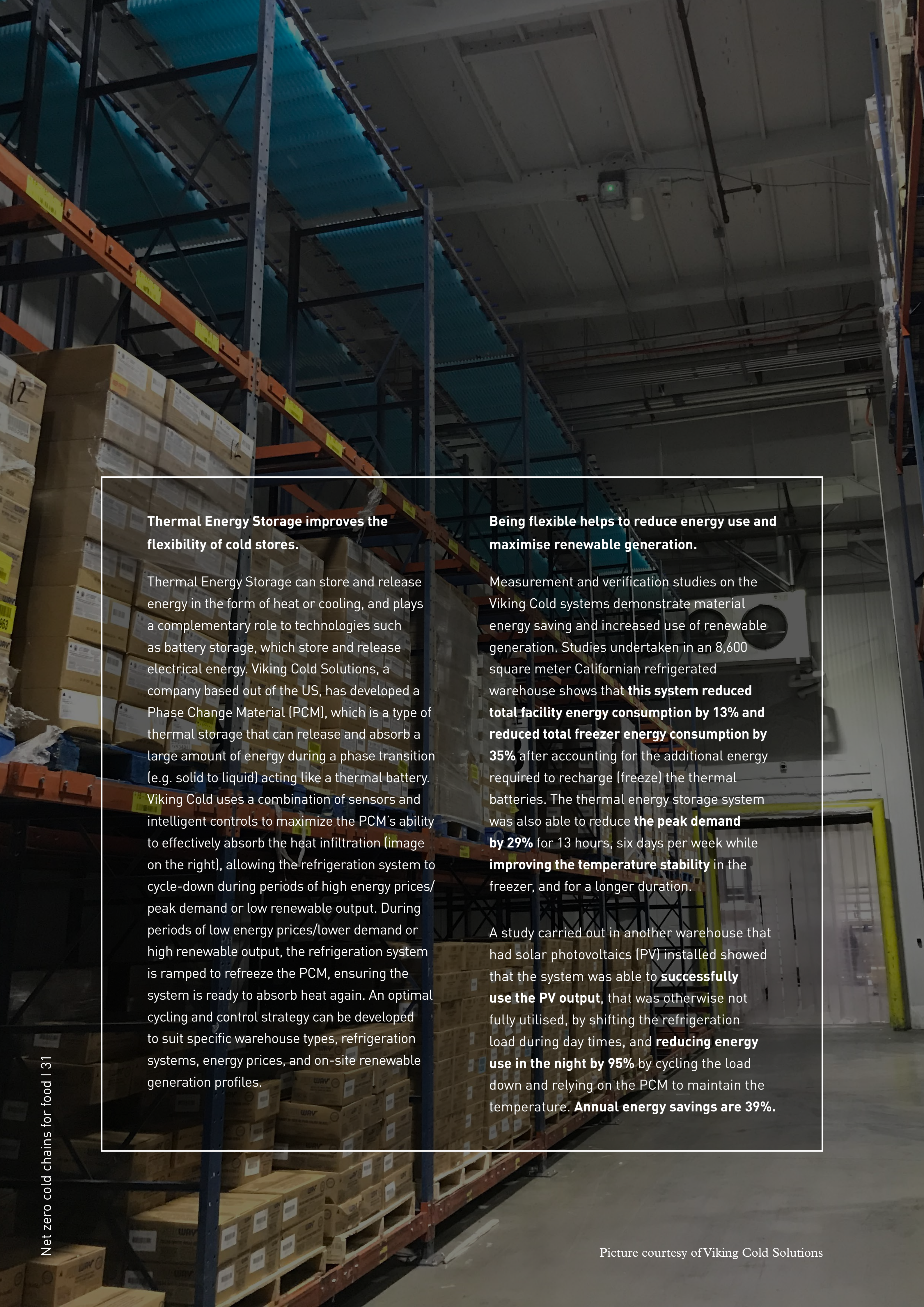
Case Study 1: Insights on flexible and smarter cold stores technologies

Making cold stores smarter and flexible using thermal storage

Why make cold stores flexible?

Low-temperature cold stores are an integral part of a cold chain helping to store perishable food safely and linking them to distribution and retail. Such facilities are also energy intensive and can account for a significant proportion of demand in areas with high commercial, industrial, or retail concentration. Energy is also one of the biggest components of a refrigerated warehouse's operating budget. With the rapid increase in deployment of renewables like wind and solar, the electricity system increasingly relies on generation and demand to be flexible (move up and down) to help manage the system.

This presents opportunities for refrigerated warehouses to contribute positively to ease pressure off the system and reduce energy use and costs while doing so. The key challenge is to make a refrigerated warehouse's demand flexible at certain times while maintaining the temperature guidelines for the food products to be stored safely.



Thermal Energy Storage improves the flexibility of cold stores.

Thermal Energy Storage can store and release energy in the form of heat or cooling, and plays a complementary role to technologies such as battery storage, which store and release electrical energy. Viking Cold Solutions, a company based out of the US, has developed a Phase Change Material (PCM), which is a type of thermal storage that can release and absorb a large amount of energy during a phase transition (e.g. solid to liquid) acting like a thermal battery. Viking Cold uses a combination of sensors and intelligent controls to maximize the PCM's ability to effectively absorb the heat infiltration (image on the right), allowing the refrigeration system to cycle-down during periods of high energy prices/ peak demand or low renewable output. During periods of low energy prices/lower demand or high renewable output, the refrigeration system is ramped to refreeze the PCM, ensuring the system is ready to absorb heat again. An optimal cycling and control strategy can be developed to suit specific warehouse types, refrigeration systems, energy prices, and on-site renewable generation profiles.

Being flexible helps to reduce energy use and maximise renewable generation.

Measurement and verification studies on the Viking Cold systems demonstrate material energy saving and increased use of renewable generation. Studies undertaken in an 8,600 square meter Californian refrigerated warehouse shows that **this system reduced total facility energy consumption by 13% and reduced total freezer energy consumption by 35%** after accounting for the additional energy required to recharge (freeze) the thermal batteries. The thermal energy storage system was also able to reduce **the peak demand by 29%** for 13 hours, six days per week while **improving the temperature stability** in the freezer, and for a longer duration.

A study carried out in another warehouse that had solar photovoltaics (PV) installed showed that the system was able to **successfully use the PV output**, that was otherwise not fully utilised, by shifting the refrigeration load during day times, and **reducing energy use in the night by 95%** by cycling the load down and relying on the PCM to maintain the temperature. **Annual energy savings are 39%.**

Picture courtesy of Viking Cold Solutions

Case Study 2: Example of novel financing and business model approaches to cold chains to improve affordability

Making net zero cold chains affordable

Commercial innovation in net zero cold chains is critical to drive uptake of solutions in developing countries where affordability and accessibility to cold chain solutions are an issue. Three examples below showcase innovative leasing and pay-as-you-go models developed by companies operating in Africa, Asia, and Latin America.

ColdHubs is a social enterprise based out of igeria who provide an end-to-end service to install and maintain solar-powered walk-in cold rooms. They offer a simple pay-as-you-store model to farmers for the usage of their facilities. They position their facilities close to farm clusters and markets and charge a fee for every 20kg crate stored in the cold room per day. Their refrigeration units use a natural refrigerant (propane) which has a GWP of only three, thereby significantly reducing the climate impact.

InspiraFarms is a UK based company who design and finance portable and remotely connected cold storage and pack houses. The facilities are either grid connected or powered by solar PV and supported by thermal storage systems. In addition to an asset finance model, they offer use of their facilities via a 'pay-as-you-chill' model that is priced according to the volume and type of product stored. Their systems are also highly energy efficient and claim to use 70% less energy relative to conventional systems.

Case Study 3: Example of strategic approach to cold chain development affordability

Strategic approach to cold chain development

India is one of the largest producers of bananas but also has high post-harvest losses.

Bananas are one of the most consumed fruits on the planet with over 114 million tonnes produced in 2017. India grows a significant proportion of the world's bananas and has been producing an average of around 29 million tons between 2010 and 2017. While the sector accounts for a significant portion of land under cultivation and provision of employment, the high post-harvest loss of bananas – at around 20-30% - accounts for significant wastage, which negatively impacts the income potential of farmers.

Picture courtesy Danfoss Cooling

Collaborative effort across industry helped to identify the need for and value of integrated cold chains.

Danfoss and the Confederation of Indian Industry (CII) established a taskforce to address the challenges around food loss reduction. The task force carried out a first-of-its-kind assessment of the overall Indian food market and identified the state of Tamil Nadu as the area of largest post-harvest loss of bananas. A further detailed study on bananas in Tamil Nadu by the taskforce identified that better post-harvest management, including the development of an integrated cold chain and better market connection, could deliver transformative change including:

- **a 15% reduction in waste/ increase in saleable of product;**
- **a 10% increase in the price of bananas due to better quality; and**
- **a 25% increase in price for 10% of the produce through better grading and packaging.**

Cold chain development has unlocked benefits for farmers.

Danfoss has implemented the recommendations from the taskforce to develop pre-cooling, cold storage post-harvest, and ripening chambers (image below) that help to ensure bananas go through controlled ripening. These interventions have resulted in **three times higher value for the farmers and a wastage reduction of nearly 20%.** The underlying components and level of automation used in these ripening chambers have also enabled up to **25% reduced energy costs**, highlighting the value of installing energy-efficient cooling equipment.

Survey Insight Box 5: Contributions to efficient, climate-friendly cold chains

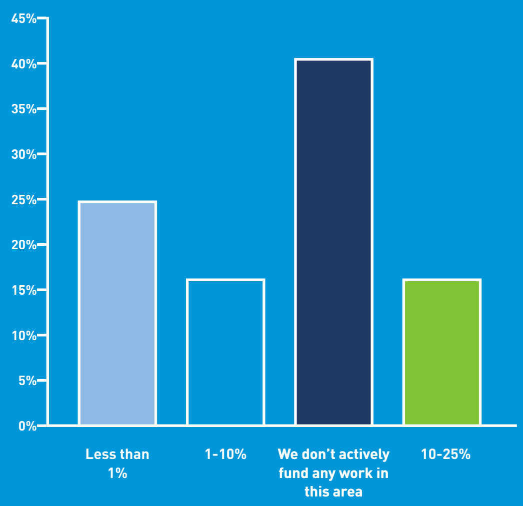
Survey responses on contribution to efficient, climate-friendly cold chains

Few of the survey respondents actively contribute financially to the development of efficient, climate-friendly cold chains. For those who do invest in this sector, their contribution corresponds to less than 1% of their total annual budget.

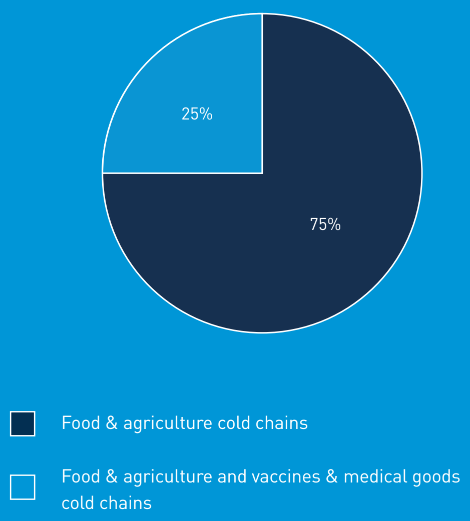
'Lack of clarity about the right solutions', 'lack of clear evidence on impact', 'strong evidence but the organisation has other priorities' or 'this area is not within the strategy remit' were the reasons given for survey respondents not being more active in this area.

75% of respondents who work in this area are focusing on the food and agriculture cold chains. No respondent is active in vaccines and medical goods cold chains only.

Pecentage of total annual budget/funding of respondents goes into efficient, climate-friendly cold chains



Sector of respondent's contribution to efficient, climate-friendly cold chains



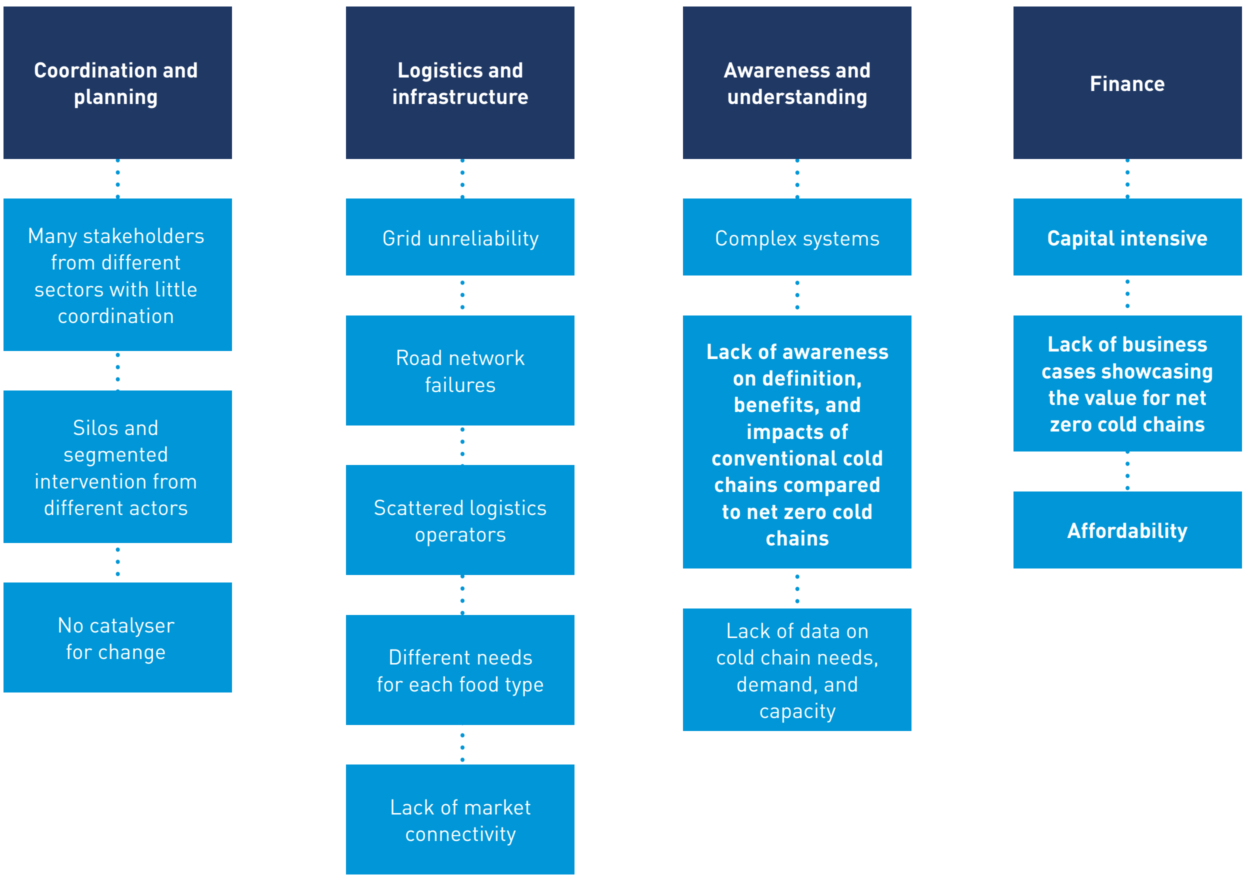
Respondents: 22 respondents shared information on their financial and sector involvement in efficient, climate-friendly cold chains.

2.1 Barriers to developing efficient, climate-friendly cold chains

There are a range of general barriers that challenge cold chain development and some that are specific to efficient, climate-friendly cold chains. Challenges vary depending on the economic development of a country.

Where generic barriers affect conventional cold chains, these can be more acute for net zero cold chains in developing country contexts. As an example, cold chains are capital intensive and this additional cost in lower-income countries represents a bigger burden.

Figure 11: Key barriers to cold chain development and efficient, climate-friendly cold chains (in bold)



Cold chains are an integral component of food and energy systems making it difficult to separate them out and shape them. Food systems are complex socio-technical systems consisting of several interconnected technologies, policies, markets, actors, and networks, that are evolving in response to the challenges faced by them. The key property of complex systems such as these is the difficulty in disentangling component level changes (e.g. cold chains) and system level effects (e.g. food security, nutrition, etc). Traditional approaches to interventions in complex systems have been reductionist and have taken a siloed approach, such as emissions, food loss, or nutrition depending on the primary interest of the organisation. As cold chains have interactions across the whole of the food system, from production through to consumption, it is hard to identify particular leverage points for interventions. In addition, they also interact with the energy system by way of being a key source of demand all through the value chain. This inherent complexity has led to piecemeal projects testing cold chain technologies or interventions (conventional and clean) in silos, preventing the build-up of robust evidence of system-level value add to support replication or scale-up.

The logistics network is complex and is getting more complex as market trends and country priorities shift from feeding populations to providing nutrients from diversified food products. The lack of road networks and the reliability of the electricity grid are also a barrier in many mid- or low-income countries. In some instances, an interrupted cold chain due to unreliable grid may result in worse outcomes than having no cold chain in the first place. Therefore, **planning a net zero cold chain must consider the reliability of grid and road network systems.**

Cold chains have varied definitions and are marked by low levels of awareness on what they entail and how they can add value. Due to their complexity and diversity in forms, there is a lack of alignment on good or best practices in developing end-to-end cold chains. In addition to that, the lack of precise data on capacity required, temperature needs per commodity, and anticipated demand, makes planning difficult.

Cold chains are capital-intensive technologies with limited access to finance and the business case for switching to new efficient, climate-friendly technologies has not yet been widely proven. In practice, the industry has dealt with the development of this chain by segment, either cold room or refrigerated transport. The lack of value addition and business-case focussed evidence prevents the uptake of both conventional and net zero cold chains.

3. The case for philanthropic action

With a few exceptions, cold chain development is primarily driven by the technology supply chain. In India, for example, a more joined-up effort is taken between government, logistics companies, and the farming community.

Philanthropy is already involved in supporting cold chains. For instance, K-CEP has supported the sector by working with the World Wildlife Fund (WWF) to develop solutions for the fishing sector in East Africa[33]. Interventions at this stage have focused on single approaches to test technology deployment or awareness creation on the scale of impact of cold chains.

Therefore, opportunities to move towards a more cohesive approach that is able to address deployment and long-term challenges at different socio-economic country contexts and geographies exist. Based on our survey, 75% of respondents (including non-funders) are active in supporting efficient, climate-friendly food cold chains, and 25% support both food and vaccine related efficient, climate-friendly cold chain sectors. The majority of those interested in having future activity in this space plan on being involved in food cold chain development.

Survey Insight Box 6: Perception insights on philanthropy‘s role

Perceptions on the type of intervention for efficient, climate-friendly cold chains

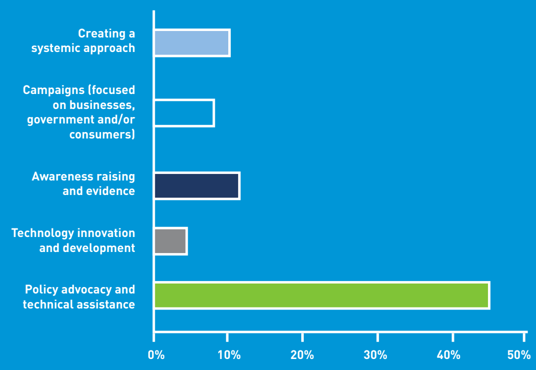
Respondents were asked to rank the highest impact areas for developing efficient, climate-friendly cold chains of five activities:

‘Policy and regulation’ and ‘Technology innovation and development’ were ranked as having the highest impact to deploy efficient, climate-friendly cold chains. This highlights the importance of market pull and a technology push approach to developing this infrastructure.

Rank	Highest impact intervention
1	Policy and regulation
2	Technology innovation and development
3	Finance
4	Creating a systemic approach with a joint coalition
5	Awareness raising and evidence

Participants were asked to share their perception on the role of philanthropy in helping the development of efficient, climate-friendly cold chains:

45% of participants considered 'policy advocacy' and 'technical assistance' as the main activity philanthropy should focus on. Opinions varied between finance and technology demonstration as well as seeing philanthropy as the key player to bring stakeholders together:



Survey quotes:

"Philanthropy could create evidence through the development and implementation of pilot cold chains in countries with the biggest predicted growth rate for cold chains. It should also raise awareness and build capacities for the development of conducive policies for climate-friendly cold chains."

"Arrange for innovative financing to promote business models that would use transformative and contextual technologies keeping in mind the needs of local market and population and resist the urge to import western models that are many times far more energy-intensive and wasteful."

"Coordinating between key stakeholders and providing independent and clear information to support change is critical."

"Using philanthropic funding to set up risk mitigation mechanisms that can leverage private funding (e.g. payment guarantees to enable technology providers to offer as-a-service and other financial solutions to their clients)."

"I think that philanthropy has a role to play in capacity building and awareness, but business cases and technologies have to be taken care by the private sector on economically sound basis."

Respondents: 33 participants responded to the survey questions on philanthropic action.

The survey and interview feedback summarised above were reasonably well aligned on high impact areas for efficient, climate-friendly cold chains development – policy development, technology innovation, and finance – and the areas identified as most relevant for philanthropy to support development in. While the survey numbers are modest with respect to the cold chain community, the feedback gathered from funders and key supply chain stakeholders highlights the need for philanthropy to drive action to pave the way for the private sector to scale up.

3.1 Options for supporting climate-friendly cold chains for food

The asymmetric growth of cold chains across countries of different income segments also creates a strong rationale for tailored approaches to catalysing efficient, climate-friendly cold chains. This sets up broad needs across the three income groups and key needs across them:

High-income countries – the key need in high income countries where cold chain infrastructure exists is mainly relating to retrofitting it with climate-friendly refrigerants, energy efficiency measures, and improving the demand flexibility of these sites to integrate effectively with renewables. There is also a need to ensure such measures are financially attractive to help drive wider uptake.

Middle-income countries – the key need in middle-income countries that are already on the journey to cold chain build out is to improve awareness of and confidence in existing and innovative efficient, climate-friendly cold chain solutions. It is also important to work with governments and industries to help develop a systemic approach to cold chains that maximise food system, environmental, and social objectives.

Low-income countries – low-income counties require strong government policies and regulation to incentivise the build out of cold chains in parallel with increasing awareness of cold chains through integrated demonstrators and skills development. There are wider enabling measures, such as developing the agri-food sector, improving access to finance, market development, logistics development (roads and ports), and improving access to energy, that needs to happen for the cold chains to scale up and return value to different stakeholders.

Cold chain development as outlined earlier in the report is generally a result of complex interplays between economic growth and agri-food sector and retail sector development, as well as government policy around food standards and wider logistics. This results in a busy stakeholder and partner landscape across all those areas in which to catalyse development.

Table 3 below outlines some options for philanthropic action across the cold chain segmented by different income groups. This list has been gathered on the back of the expert interviews, surveys, and desk research. Additionally, the table also provides some initial indication of how these different options map to their applicability for philanthropic support and some considerations for partnerships to be able to deliver these effectively.

Table 4: Mapping cold chain development needs with applicability for philanthropies based on stakeholder feedback

Philanthropic action	Low income	Middle income	High income	Applicability for philanthropy	Key partners w
Support country-level cooling needs assessments based on food system development.	Highly applicable	Somewhat applicable	Not applicable	Medium	National governments, farmer associations, academics, retail
Support improved data collection on clean cold chain operations and benefits across a range of commercial, social, and environmental outcomes.	Highly applicable	Highly applicable	Highly applicable	Medium	Academics, cold chain supply chain
Support innovators to develop and commercialise clean cold chain solutions.	Highly applicable	Highly applicable	Somewhat applicable	Medium	Innovators, cold chain supply chain, investors
Support creation of cross-government and industry groups for cold chain development.	Highly applicable	Highly applicable	Not applicable	High	National government departments, farmer associations, cold chain supply chains, retail associations
Support development of integrated policy frameworks for clean cold chains.	Highly applicable	Highly applicable	Somewhat applicable	High	National governments
Support demonstrations that showcase the technical capability of, and build confidence in, clean cold chain technologies.	Highly applicable	Highly applicable	Somewhat applicable	Medium	Innovators
Support demonstrations to showcase the business case for clean cold chains to catalyse investment.	Highly applicable	Highly applicable	Highly applicable	High	Innovators, cold chain supply chain, investors
Help improve access to finance for clean cold solutions (retrofit and new build).	Highly applicable	Highly applicable	Somewhat applicable	Med	Investors, cold chain supply chain
Support skills-development programmes for clean cold chains.	Highly applicable	Highly applicable	Somewhat applicable	Low	Cold chain supply chain
Food standard and safety policy and certifications development.	Highly applicable	Somewhat applicable	Not applicable	High	National governments, cold chain supply chain

Key:

- Action highly applicable to a country category
- Action somewhat applicable to a country category
- Action not applicable to a country category

3.2 Recommendations for philanthropic action

As there are numerous intervention points and opportunities across cold chains and countries, it is important to identify effective entry points for philanthropy and to build partnerships to test approaches, build momentum, and then scale action.

Given that there are already significant cold chain GHG emissions in developed countries, there is an opportunity for philanthropy to help 'bend the curve' on these existing emissions and address the challenges with existing cold chain infrastructure. This would help to demonstrate net zero cold chains solutions and build confidence in policy, technology, business models, and finance solutions that can unlock their deployment. In countries where significant new cold chain infrastructure is forecast, the opportunity for philanthropy is to help these countries shift to a path to net zero cold chains and leapfrog the need to deploy existing cold chain infrastructure with its significant environmental impacts. There is an opportunity for philanthropy to pursue poverty reduction and helping to achieve multiple sustainable development goals (SDGs) alongside these climate mitigation efforts, building a coalition of philanthropic foundations and individuals with intersecting interests in climate mitigation, food security, and poverty alleviation.

As cold chains are a complex system that interact with many other systems, learning-by-doing approaches offer the most value in terms of evaluating benefits of interventions and consolidating learnings. Additionally, the lack of integrated approaches could minimise the development benefits around poverty alleviation, nutrition, and wider economic development owing to incomplete build-out of cold chains. This sets up the rationale for philanthropy to play a 'systems integrator' role in the short term by bringing together disparate actors and helping to demonstrate the value of end-to-end net zero cold chains.

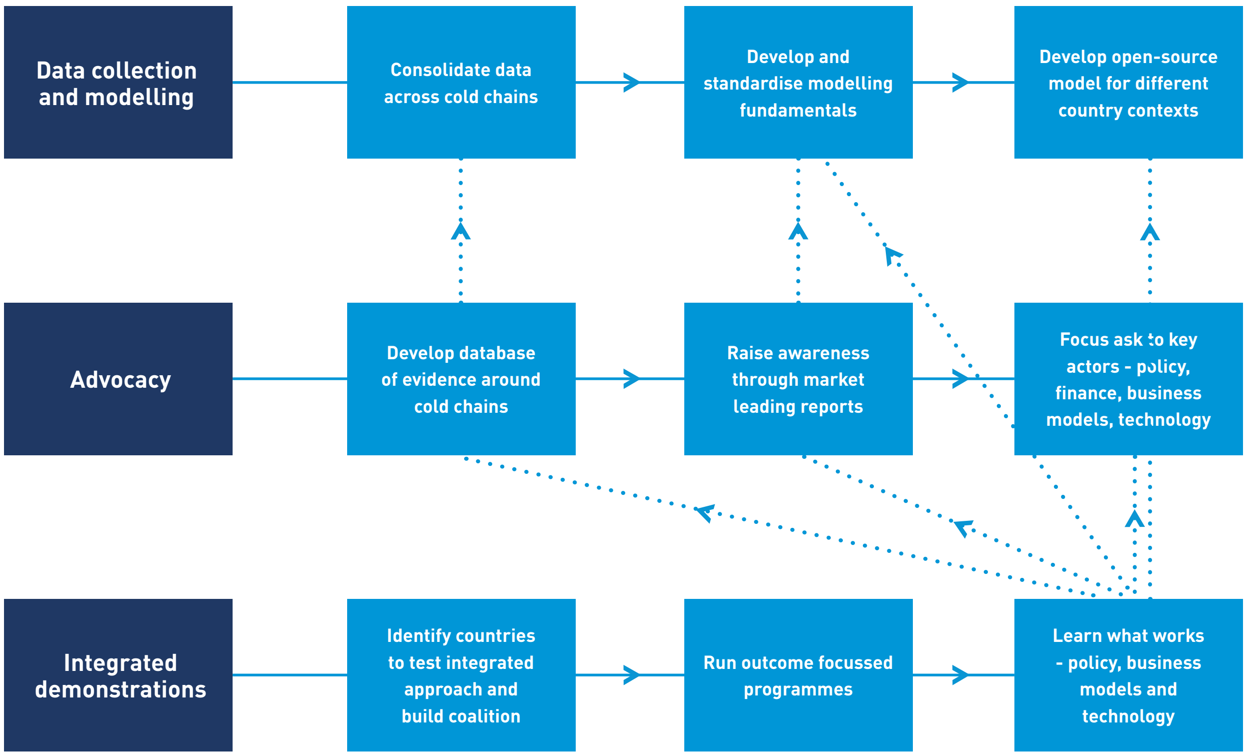
As the outcomes of cold chain deployment are critical (food security, farmer income, low food loss, etc.), and the deployment of cold chains don't necessarily guarantee these, an outcome-focussed approach from philanthropy will help maximise these positive environmental and social impacts.

Modelling and data collection are essential, but are currently scarce. Integrating them into such an applied approach will generate evidence that is more usable than activities that solely focus on addressing data gaps.

There are three key recommendations below, as visualised in *Figure 12*, which are mutually reinforcing and could offer both short- and long-term climate and development impact for philanthropy.

Given that there are already significant cold chain GHG emissions in developed countries, there is an opportunity for philanthropy to help ‘bend the curve’ on these existing emissions and address the challenges with existing cold chain infrastructure

Figure 12: Visualisation of a systems integrator approach for a philanthropic intervention to develop efficient, climate-friendly cold chains



1. Data collection and modelling

One of the key barriers to net zero cold chains is supporting data and evidence on their social, economic, and environmental value. Philanthropy can play an important role in addressing this barrier by supporting the development of:

- a database of different net zero cold chain building blocks, their performance, impact on energy use, GHG emissions (against standard baselines), benefits for different stakeholders (farmers, developers, etc.), and costs;
- in-depth qualitative modelling on different social, economic, and cultural contexts of the trade-off between cold chains emissions and food loss reduction; and
- an open-source quantitative model underpinned by the database and research above to help estimate the value of clean cold chains in terms of food loss and GHG emissions reductions, which can be applied to different country contexts.

2. Integrated demonstration of net zero cold chains

Philanthropy can also play a key role in addressing the lack of integrated demonstrations of net zero cold chains to help narrow the data and evidence gap on 'what works'. These demonstrations would aim to show how technology, business models, and finance solutions can unlock net zero cold chains. This could be delivered through a three-phase approach starting with two or three focus countries to build an integrated programme that aims to catalyse net zero cold chains. This could be a combination of developed countries to mitigate existing GHG emissions and developing countries to mitigate forecasted GHG emissions growth. Once the programme is designed with key stakeholders across government, the private sector, the investor community, and relevant research organisations, a strong focus on continuous learning and evaluation will help build up insights to inform next steps. This will also be critical to validate and improve the deliverables from the 'improving awareness and data' strand. High-level details on the three phases are outlined below along with an initial view of time scales and intended outcomes.

Phase 1: Country selection (4–6 months)

This phase helps to select suitable countries in which to design and run the programme. This needs to consider the nature of the agri-food sector, consumer demand (present and future), broader economic growth strategy, and energy system infrastructure. The assessment process should also consider willingness to engage from key government departments such as agriculture, energy, environment, trade, and transport. The selected countries should enable the programme to deliver learnings at scale to act as a reference case to aid scale up and replication. The countries considered could be a mix of low-medium- and high-income countries.

Another important consideration is for such countries to potentially showcase the ability to leapfrog conventional cold chain technologies in an affordable manner. As national governments and development agencies in high-income countries support domestic and international decarbonisation efforts, a coordinated effort between philanthropy and selected governments could drive action quicker.

Phase 2: Programme design and coalition building (12–18 months)

Once the pilot countries have been identified, the programme design and coalition-building phase can begin. This could involve starting a scoping programme to identify a range of high-impact opportunities to deliver on goals and targets for net zero cold chain development in the selected countries. These goals (environmental, social, and economic) can either be pre-agreed with the national government and other key stakeholders, such as farmers associations, or be derived through the scoping exercise. It is important for the scoping exercise to ensure a systems approach is undertaken and does not just focus on the technical or infrastructure aspects of cold chains. The program should go beyond demonstrating the technical capability of different solutions to proving the commercial value (and mechanisms to support this) to different stakeholders (cold store operators, investors, farmers, traders, etc.) to ensure continued development post-pilot.

Once the range of opportunities have been identified, along with their estimated benefits, a programme can be developed to deploy said opportunities with an outcome-led approach across environmental, social, and economic factors. For example, to reduce total emissions of cold chains by [y]%, reduce post-harvest loss of commodity [x] by y%, increase value of commodity [x] to farmers by [y]%, etc. The programme should include a sizeable role for continuous evaluation and learning to ensure the programme is agile and generates robust evidence.

Phase 3: Programme deployment and continuous learning (48–60 months)

As the programme gets underway, the learnings coming out – in terms of what is and isn't working – will help to build a body of knowledge and fill data gaps. This data will also be key to validate and improve any quantitative models, such as the one recommended above. The key objective of the programme for philanthropy would be to catalyse action and build momentum sufficiently to enable private sector actors and governments to replicate and scale up these approaches and lessons learnt. Given the complex nature of cold chains, simple replication of actions will be difficult and won't guarantee similar results, so the learning and dissemination in this phase will need to be sensitive to these challenges. The aim is to catalyse action and engagement from governments and the private sector on larger, integrated programmes that allow philanthropy to step back and focus on specific aspects of catalysing efficient, climate-friendly cold chains like policy advocacy, awareness raising, and technology innovation support.

3. Supporting advocacy for efficient, climate-friendly cold chains development

According to the survey results of this survey, cold chains are not yet seen as a top priority in terms of climate change mitigation. It is therefore important to raise the profile of the sector, increase the awareness of existing and innovative net zero cold chain solutions, and ensure this information is available widely.

Key areas of support could include:

- a consolidated database of net zero cold chain deployments through global research and a collection of evidence. This database should be accompanied by regular knowledge briefs that highlight best practices and share evidence on the benefits of efficient, climate-friendly cold chains;
- a programme of engagement with financial institutions that fund cold chains development, to understand needs and challenges, and use it to develop business and investment case toolkits and other support for net zero cold chains development;
- leveraging the awareness raised and momentum built through the activities above to develop a synthesis report – similar to the '*Future of Cooling*' by the International Energy Agency and '*Chilling Prospects*' by Sustainable Energy for All (SEforALL) – that focuses on efficient, climate-friendly cold chains; and
- incorporating action on efficient, climate-friendly cold chains in policies and standards such as national cooling action plans and nationally determined contributions (NDCs).

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