Cool Coalition

STATUS OF THE GLOBAL FOOD COLD-CHAIN: SUMMARY BRIEFING

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CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

MINISTERO DELLA TRANSIZIONE ECOLOGICA

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Cool Coalition in collaboration with the Climate & Clean Air Coalition (CCAC), United Nations Environment Programme (UNEP), United Nations Food and Agriculture Organization (FAO), and the Ozone Secretariat, with the support of the Italian Government, are producing a status report on the global food cold-chain, which will include case studies to show the current state and development across areas such as technologies, design approaches, finance and business models, policy, and planning. This brief is a short summary of the full report that will be published in December.

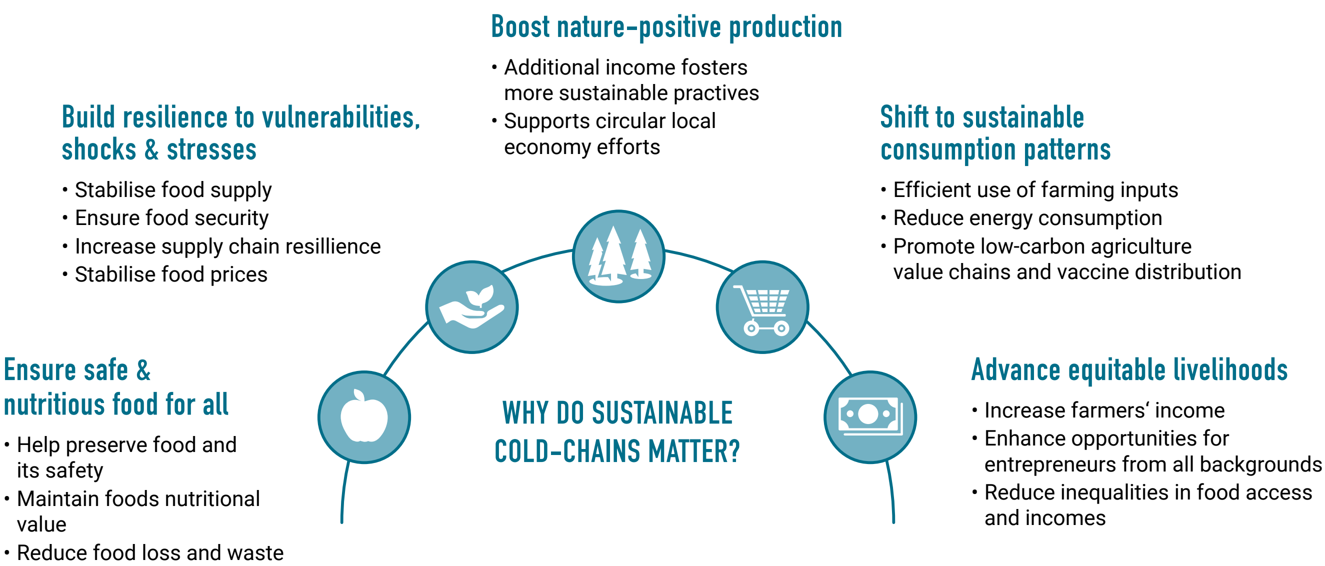
SUMMARY[1]

"Food saved is as important as food produced" summarizes the key drivers of a sustainable and resilient agri-food system. Feeding the world's growing population will require not only producing more food, but also ensuring that the food that is being produced is not lost or wasted. To achieve this, significant improvements are needed in the food cold-chain – the temperature-controlled transport, postharvest management, storage and distribution system that ensures that perishable food and/or temperature-sensitive products are kept at their optimum temperature and environment to maintain their quality, nutritional value, and safety, from source to destination.

Increasing access to the food cold-chain is critical to breaking millions of people out of the vicious cycle of hunger and poverty and to meeting the challenge of feeding 2 billion additional people by 2050. However, the current cold-chain capacity is distributed unevenly across countries, and conventional cold-chains are typically energy intensive and polluting. The refrigeration equipment used in the food cold-chain is responsible for an estimated 1 per cent of global greenhouse gas emissions worldwide, accounting for both direct and indirect emissions. Developing more sustainable cold-chains is key for improving human well-being, boosting economic growth and delivering socioeconomic development through the United Nations Sustainable Development Goals, while simultaneously achieving the targets of the Paris Agreement and the Montreal Protocol.

Making the food cold-chain more sustainable will require taking a holistic, systems approach to meeting our cooling needs. It is about more than installing solar powered cold rooms at the farm gate or chiller cabinets that use refrigerants with lower global warming potential in supermarkets. Among other steps and measures, it includes developing and strengthening the skills and the business and financing models that underpin the investment in cooling equipment.

Figure 1: **Why do sustainable cold chains matter?**



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KEY RECOMMENDATIONS

- Take a holistic, systems approach to cold-chain provision, recognizing that cooling technologies alone are not sufficient to make an efficient cold-chain.
- Undertake a cold-chain needs assessment and develop a National Cooling Action Plan to provide the underlying direction for holistic and sustainable cold-chain and cooling infrastructure creation and rationalise cold-chain programmes across ministries
- Develop five-year plans, missions, policies and dedicated agencies/ departments, and provide financial assistance and capacity support for all required cold-chain components, with the aim to bring mobility in cold-chain and achieve seamless movement of agricultural produce from farm to fork
- Build necessary skills and capacity as well as finance and business models in developing countries to support industry's engagement and technology deployment at scale.
- Run large-scale system demonstrations and use "digital twins" to design and show how interventions can work together to create sustainable and resilient solutions for scaling.
- Quantify and value the broader socioeconomic impacts of sustainable cold-chains such as income, economic growth, health, etc.

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1 BACKGROUND AND CHALLENGE

Food production will need to increase significantly in order to feed the expected human population of 9.7 billion in 2050. This would require closing the current gap between global food supply and demand of 56 per cent[2] relative to 2010 levels (*United Nations 2019; World Resources Institute 2019*). In addition to producing more food, feeding the world's growing population will mean ensuring that the food that is being produced is not going to waste.

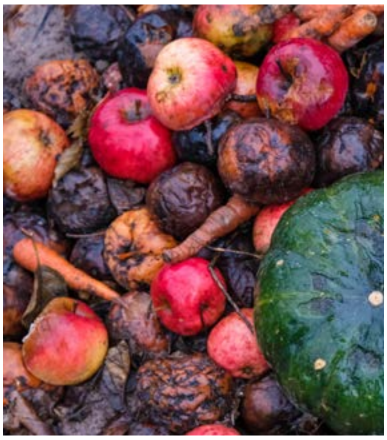
According to the United Nations Food and Agriculture Organization (*FAO*), around one-third of the food produced for human consumption currently gets lost or wasted, costing the global economy an estimated $936 billion a year (*FAO 2014a*). Lack of effective refrigeration directly results in the loss of 475 million tons, or 13 per cent, of total food production; this is enough to feed around 950 million people in a world where 811 million people are hungry and 2 billion suffer from food insecurity *(International Institute of Refrigeration [IIR] 2020; FAO et al. 2020*).

The unavailability of robust cold-chains to maintain the quality, nutritional value, and safety of food products has ramifications for people's health, particularly in the developing world. However, this is an integrated global problem. For example, in 2019, UK imported 84% of fruits and 47% of vegetables (*Department for Environment, Food & Rural Affairs, 2020*). On the other hand, in India, the Agricultural Export Policy, introduced in 2018, aims to double agri-exports to $60 billion by 2022 and reach $100 billion in the next few years thereafter (*Government of India, 2018*). Similarly, Rwanda has a five-year strategy to double agri-exports by 2024-2025; this includes a nine-fold increase in high-value temperature-controlled horticulture exports (*NAEB, 2019*).

Moreover, populations in most developing countries depend heavily on agriculture for their livelihoods, making the development of cold-chain a powerful tool to boost incomes and foster economic growth. According to the FAO, post-harvest food loss reduces income by at least 15 per cent for 470 million smallholder farmers (*Rockefeller Foundation 2021*).

The food cold-chain also has implications for the global climate. The food that is currently produced and not eaten results in greenhouse gas emissions totalling an estimated 4.4 gigatons of CO_2 equivalent annually, or around 8 per cent of the global total (*FAO 2014b*). Of the total emissions impact of food loss, 1 GT CO_2e is estimated to be the result of lack or inefficiency of cold-chains (*Global Food Cold Chain Council, 2015*).

Meanwhile, the equipment used in the cold-chain itself is responsible for both direct and indirect greenhouse gas emissions. Solutions are needed to make the global food cold-chain more climate-friendly as well as more environmentally sustainable.



2 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. This figure is often misquoted as 70 per cent (UN 2019), which is the previous FAO estimate (FAO 2014a) (World Resources Institute 2019).

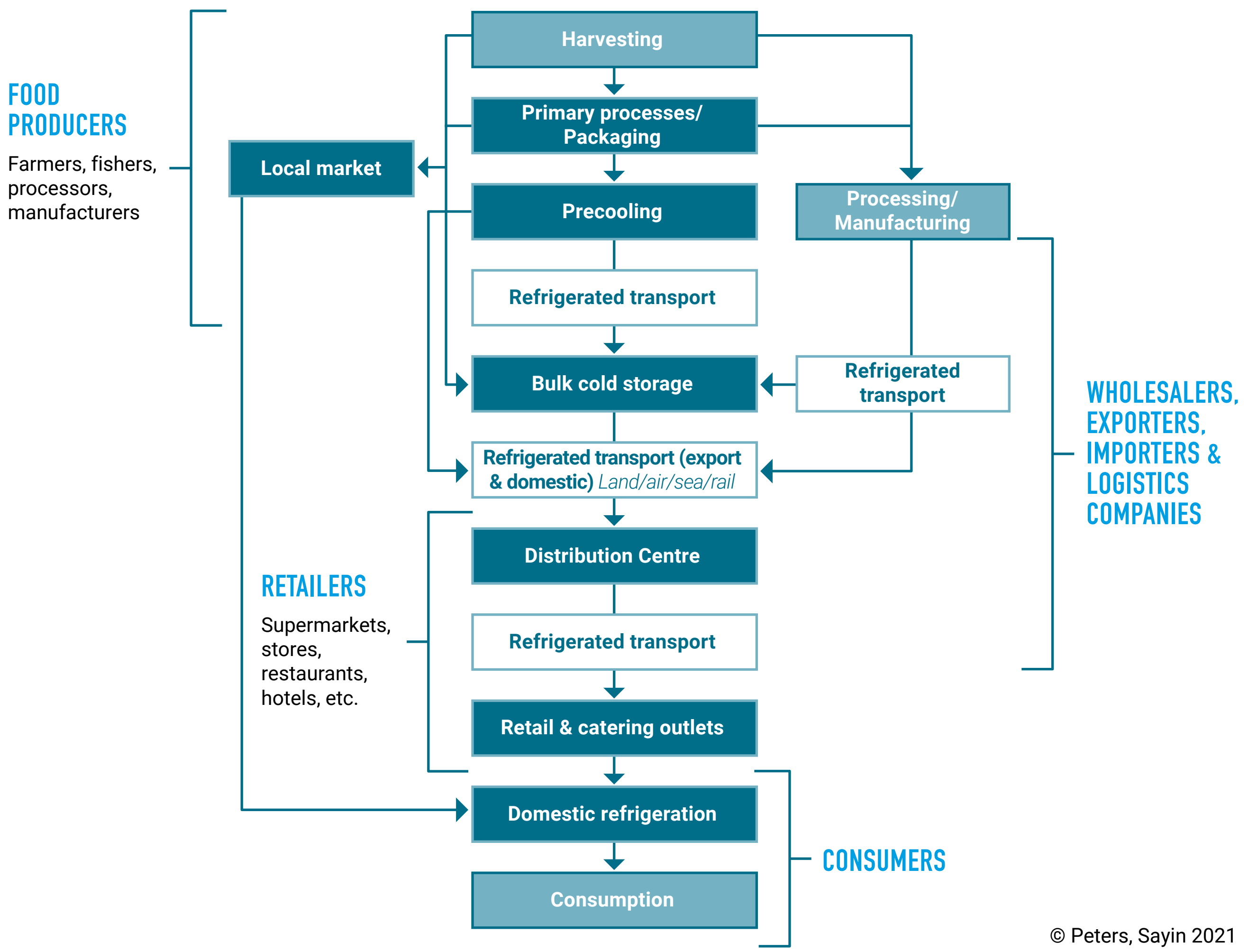
2 THE GLOBAL FOOD COLD-CHAIN

2.1 WHAT IS THE FOOD COLD-CHAIN?

The global food cold-chain is a functionally integrated temperature-controlled transport, storage and distribution system that ensures that perishable food and/or temperature-sensitive products are kept at their optimum temperature and environment – different for each depending on specifications and characteristics – to maintain their quality, nutritional value, and safety, from source to destination. It is a complex system that has many static and moving elements from "farm to fork" and that requires accountability from multiple levels, including farmers, processors, manufacturers, aggregators, distributors, retailers and consumers (Figure 2).

Apart from temperature, other environmental parameters that affect the usable or saleable life of produce and products under care – such as air humidity and composition – also need to be controlled throughout the cold-chain. Cold-chain must consider the packaging used, the type of material handling equipment and other logistic systems. To extract meaningful shelf life from the total holding life of the goods, the cold-chain works against time constraints, and thus benefits from the digitalization of its operations and monitoring activities.

Figure 2: **Typical food cold chain steps and stakeholders**



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2.2 CURRENT STATUS AND FUTURE DEMAND FOR COLD-CHAIN

The global cold-chain capacity has been growing in recent decades. The Global Cold-chain Alliance (GCCA) estimates that the worldwide refrigerated warehouse capacity totalled 719 million cubic metres in 2020; this is 16.7 per cent greater than in 2018, with North America and China accounting for most of the increase (*GCCA 2020*). However, this capacity is distributed unevenly across countries, 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 is only around 20 cubic metres per 1,000 inhabitants on average, or even less (*IIR 2021*).

The food cold-chain is more than refrigerated warehouses. For example, India's National Centre for Cold-chain Development (NCCD) estimated in 2015 that the country had less than 15 per cent of the refrigerated trucks it needed. While the number of refrigerated trucks in India has since risen to around 19,000,[3] this is still less than a third of what NCCD has proposed the country requires to meet its food cooling needs[4] (*NCCD 2015; University of Birmingham 2017*).

In the coming decades, food cold-chains are expected to expand significantly to cope with the increasing demand for perishable food products in a warming world, as well as to address current unmet needs for cold-chain, especially in developing countries. According to the Economist Intelligence Unit, based on cooling sales, industrial and transport refrigeration will be the fastest growing sub-sectors within the cooling sector, with average annual growth rates of 5.1 per cent and 4.8 per cent, respectively, between 2018 and 2030.

Analysis led by the University of Birmingham has shown that growth in the global food cold-chain will need to be dramatically higher to deliver cooling for all who need it, and therefore to meet the targets of the United Nations Sustainable Development Goals (SDGs) (*Peters 2018*). 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.

3 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 (IIR 2019).

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

2.3 ENVIRONMENTAL IMPACTS AND IMPLICATIONS OF BUSINESS-AS-USUAL GROWTH

Conventional cold-chains are typically energy intensive and polluting. The refrigeration equipment used in the food cold-chain not only releases indirect emissions from energy use (especially when generated from fossil fuel sources), but is also responsible for direct emissions from the leakage of ozone-depleting and climate-warming refrigerants during use and servicing as well as following disposal at the end of life. In total, this equipment alone is responsible for an estimated 1 per cent of global greenhouse gas emissions, globally accounting for both direct and indirect emissions (*James and James 2010*). In the absence of any intervention, emissions are set to rise significantly as new cold-chain infrastructure comes online. This poses a massive threat to achieving our climate and sustainable development goals, targets and commitments.

In the developed world, where emissions from cold-chain operations are already significant, sustainable cold-chain development with minimal environmental impact is essential to bend the emissions curve. Meanwhile, developing countries, where cold-chains are expected to expand, must avoid significant increases in emissions. This is also important to avoid putting additional pressure on already strained energy systems in countries where energy security is a major problem, and to optimize the additional investment for energy infrastructure.

Despite the surging demand and central importance of cold-chains to a functioning modern society and the many benefits they deliver, the decision criteria associated with cooling provision tends to be narrowly focused, with a focus on measuring savings from efficiency and emissions impact, and on initial investments. Although this is important, the broader societal and economic benefits from access to cold-chains are typically not incorporated and are treated as a "soft win", rather than as the core driver for provision. Prioritizing sustainable cold-chains can help address this challenge.

3 SUSTAINABLE FOOD COLD-CHAINS

3.1 WHAT ARE SUSTAINABLE COLD-CHAINS?

In the context of cold-chain development, the term "sustainability" is often used in an undiscerning and loose manner. There is limited awareness about how cold-chain contributes to a sustainable food system; how sustainable cold-chain systems should look, especially in the context of future needs and innovations; and what is needed to develop them. This is a complex issue – or a wicked problem – with diverse drivers and barriers, all interconnected, varying across regions and depending on local economic, environmental, social, cultural and political circumstances. Figure 3 shows the key drivers and barriers to a sustainable cold-chain.

Developing a sustainable food cold-chain is about more than installing solarized cold rooms at every farm gate or chiller cabinets with environmentally friendly refrigerants in every supermarket. It is about designing a cold-chain that will sustainably cater to future needs and circumstances. 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.

Among other objectives, delivering sustainable cold-chains involves minimizing the greenhouse gas emissions from cold-chains. This can be done through a variety of approaches, including:

- minimizing the demand for mechanical cooling;
- designing systems correctly and ensuring they are maintained properly.
- behaviour change (e.g., avoiding unnecessary delays in closing the doors of refrigerated spaces);
- passive cooling techniques and approaches[5] (e.g., making use of shading; food packaging to preserve freshness; applying coatings and treatments)[6]
- making use of natural, renewable and waste energy resources;
- using energy-efficient technologies with lower global warming potential (GWP) refrigerants; and
- taking a life-cycle analysis and circular economy approach to design, manufacturing, deployment, operation and end-of-life decommissioning.

5 Passive cooling systems are ones that use no energy, as opposed to active cooling systems that use energy for cooling.

6 For example, colouring all of the refrigerated vehicle bodies in London white or silver can lead to a 1.3 per cent reduction in total annual CO_2 emissions from the refrigerated transport fleet (James and James 2010).

3.2 BENEFITS OF SUSTAINABLE COLD-CHAINS

Sustainable cold-chains are key for improving human well-being, boosting economic growth and delivering socioeconomic development through the SDGs, while simultaneously achieving the targets of the Paris Agreement and the Montreal Protocol. Delivering sustainable cold-chains requires balancing environmental, social and economic benefits (Figure 4). This includes providing access for all (including poor and marginalized farmers and fishers); considering the cooling economy as a whole; and identifying synergies between sectors where cooling demand can be aggregated and/or capacity shared (Boxes 1 and 2).

Figure 3: **Key drivers and barriers to a sustainable cold chain**

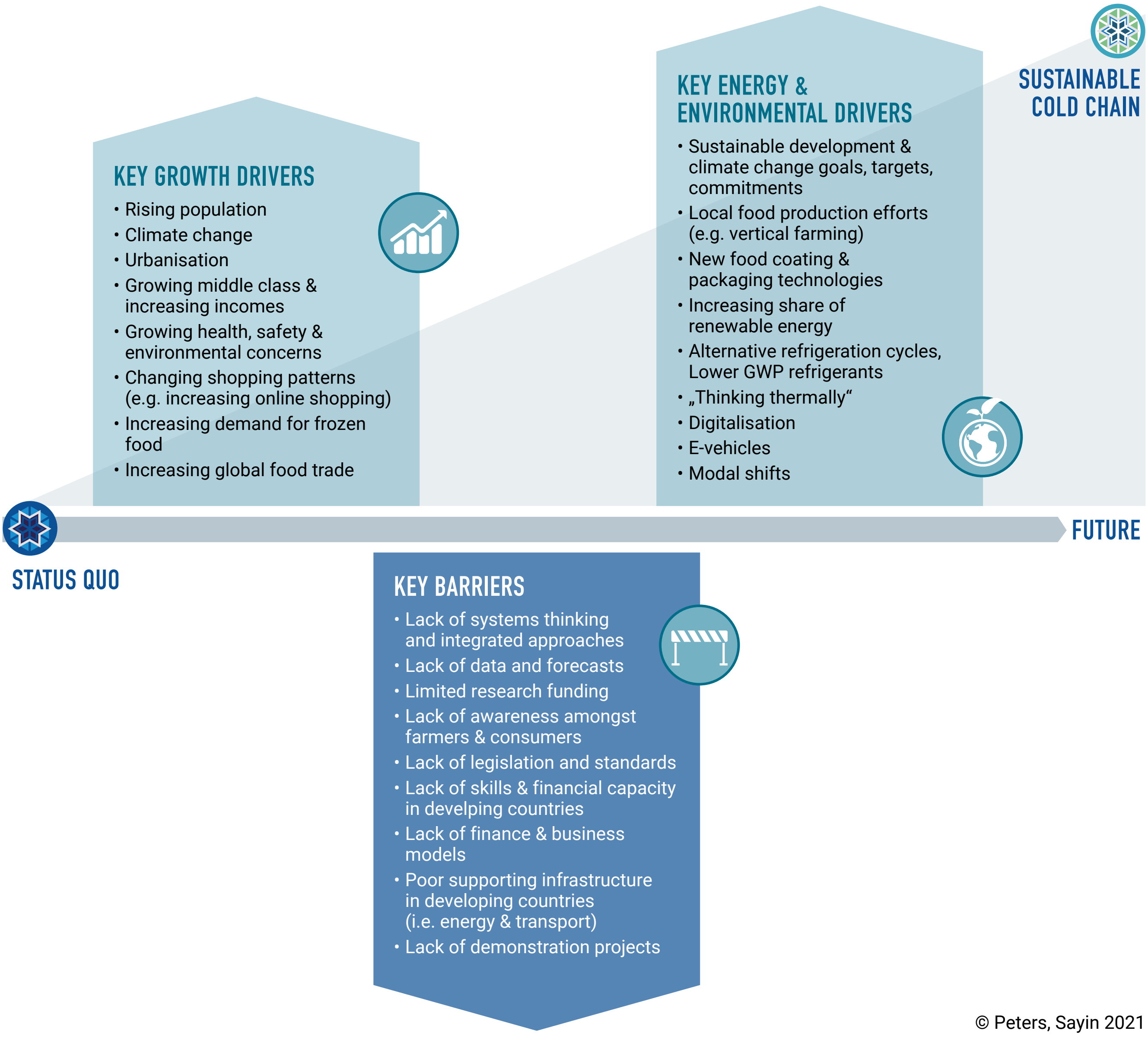
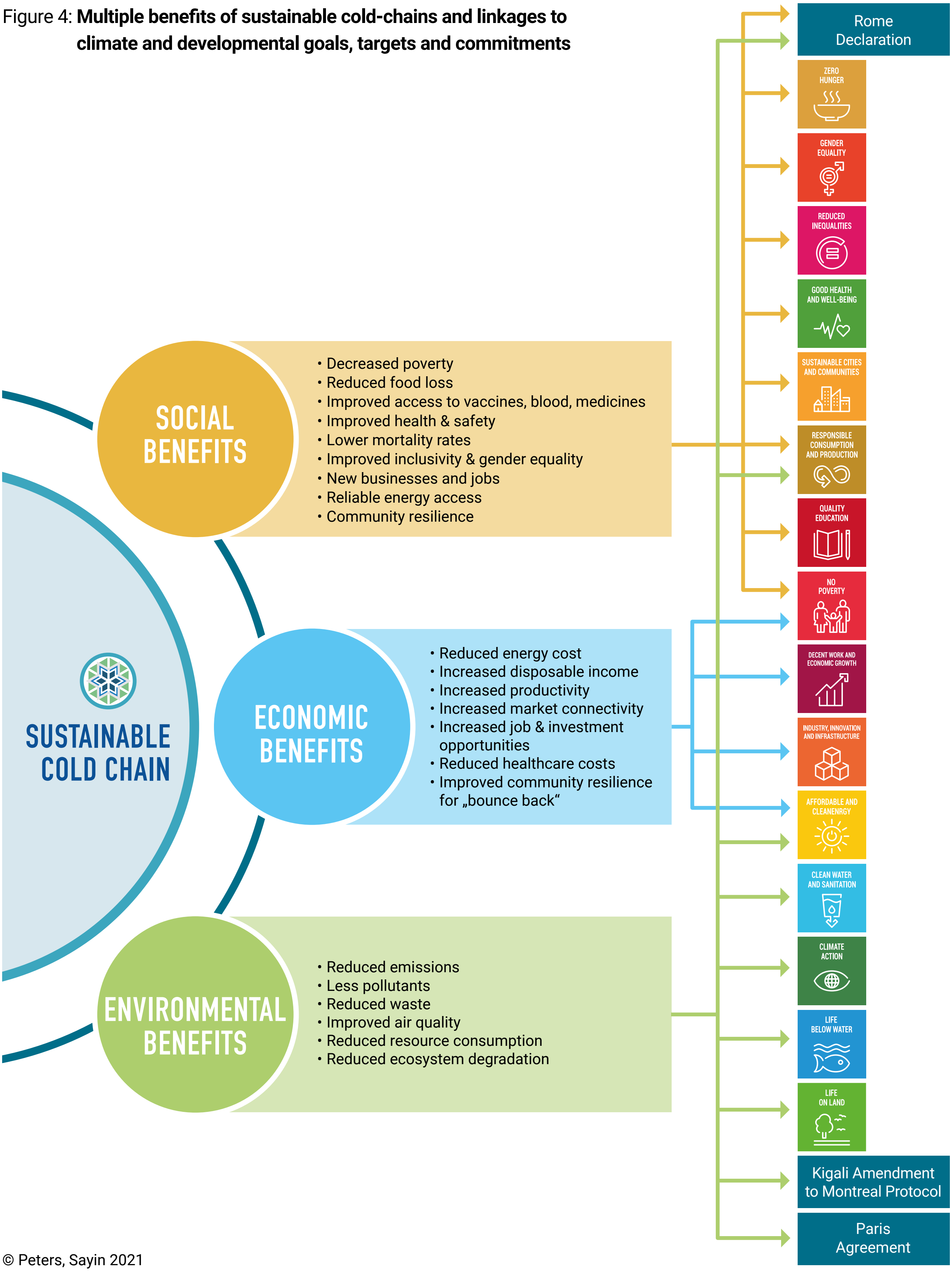


Figure 4: **Multiple benefits of sustainable cold-chains and linkages to climate and developmental goals, targets and commitments**



Box 1. Benefits of an integrated cold-chain: Kinnow pilot study in India

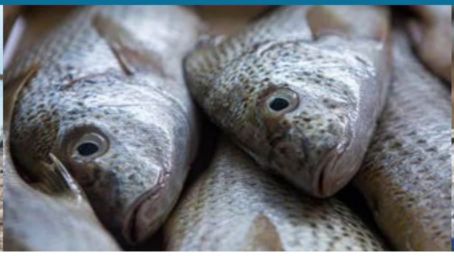
A pilot study was conducted in India with the support of the Panjab state government and executed by Carrier Transicold and Balaji Cold Stores. Balaji Cold Stores is a kinnow farm that has served as an aggregator, taking responsibility for pre-conditioning, storing and transporting the kinnow fruit. The pilot was conceived by NCCD and managed by the Indian School of Business, Mohali. The initiative provided a chain of cold storage and refrigerated transport from Abohar, in northern India, to Bangalore, in southern India, a roughly 2,400 kilometre overland journey. This allowed for ample analysis of the time- and distance-related aspects of cold-chain investment.

Given the seasonal nature and concentrated production of kinnow fruit, increasing yield and acreage has meant that production is too large for the local market. However, there are challenges in distributing to more-distant markets. The pilot has helped demonstrate that the cold-chain not only enhances the holding period of perishable produce, but also helps expand the selling radius of the produce, resulting in quicker returns with improved realization for farmers. Based on the pilot study, the integrated cold-chain interventions (precooling, cold store, reefer truck) resulted in 10 times greater profit for the farmer/aggregator, a 16 per cent reduction in greenhouse gas emissions and a four times reduction in spoilage of the fruit.

Box 2. 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.



4 OPPORTUNITIES AND SOLUTIONS FOR SUSTAINABLE COLD-CHAINS

Current cold-chain interventions often focus on low-risk, siloed approaches that aim to solve issues in isolation. However, establishing a robust and sustainable cold-chain requires the integration of many different static and mobile elements, from farm to fork, and the continuing management of those elements, ensuring minimal environmental and adverse social impact. Many opportunities and solutions exist at both the policy level and in the technology sphere to advance more sustainable cold-chains.

4.1 POLICY ACTION ON SUSTAINABLE COLD-CHAINS

The importance of cooling and cold-chains in delivering the SDGs and ambitious climate targets is increasingly recognized globally. In response, many countries have been developing and implementing national cooling plans with support from the cooling community. These include road maps and timetables for achieving a sustainable cooling economy, involving short-term and long-term considerations on refrigerant transitions (the phase-out of hydrochlorofluorocarbons and the phase-down of hydrofluorocarbons (HFCs)), reducing the cooling demand, enhanced energy performance standards and universal access to sustainable cooling (Boxes 3 and 5).

Box 3. 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 – as well as 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 Debnath 2020; Debnath *et al.* 2021).

Building on the needs assessment, many countries are developing National Cooling Action Plans 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. Several of these NCAP pioneers joined forces within the framework of the Cool Coalition* to jointly support the creation of the first comprehensive methodology for NCAP. 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.

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

* Including the UN Environment Programme, the UN Development Programme, the United Nations Economic and Social Commission for Asia and the Pacific, the Alliance for an Energy Efficient Economy, the Clean Cooling Collaborative, the World Bank Group, Heriot-Watt University, Sustainable Energy for All, Germany's GIZ, the Energy China Foundation and Clasp.

Box 4. The Cold Chain Database

An initiative by the Global Food Cold Chain Council (GFCCC) and UNEP OzonAction for developing 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 model is designed to capture the details and specifics of each sub-sector; therefore, the classification and categorization of sectors and sub-sectors was critical to ensure the comprehensiveness and inclusiveness of the model. 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.

A detailed set of questionnaires have 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 includes 5 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

Box 5. India's 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). However, up to 18 per cent of fruits and up to 13 per cent of vegetables in the country are lost because of sub-optimal and inefficient post-harvest management activities, leading to food loss worth $13.4 billion annually (Jha *et al.* 2016; Central Institute of Post-Harvest Engineering and Technology 2019).

In response, the Government of India has been seeking to develop a sustainable and integrated cold-chain across Indian states through five-year plans, missions, policies and dedicated agencies and departments, and by providing financial assistance and capacity support to upgrade the cold-chain infrastructure. For example, schemes such as the Godown Scheme, the Mission for Integrated Development of Horticulture and Pradhan Mantri Kisan Sampada Yojana have been initiated to close the gap in food cold-chain infrastructure. Such schemes aimed to provide connectivity in the cold-chain and provided financial assistance of 35%-50% for all cold-chain components like packhouse, reefer transport, ripening chamber, updated from the earlier subsidy was only available for static cold storages. Other recent interventions include the Mega Food Park Scheme and the India Cooling Action Plan (ICAP), the latter of which helped rationalise cold-chain programmes across ministries and sectors.

Three farm bills have also provided a political push towards developing a sustainable cold-chain and improving market linkages for farmers: the Farmers' Produce Trade and Commerce (Promotion and Facilitation) Bill of 2020, the Farmers (Empowerment and Protection) Agreement on Price Assurance and Farm Services Bill of 2020 and the Essential Commodities (Amendment) Bill of 2020. However, the Alliance for an Energy Efficient Economy's recent project on India's Cold-chain Policy Mapping highlighted that sustainable cold-chain development in India requires strengthening collaboration among government, private and civil society organizations to ensure the best outcome (AEEE 2021).

Box 6. UNEA-4 Resolution

The United Nations Environment Assembly (UNEA), being the highest international environmental authoritative body, adopted in its forth session, March 2019, a resolution titled "Promoting sustainable practices and innovative solutions for curbing food loss and waste". The resolution calls 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; on innovative solutions to avoid losses and minimize the impact identified in the production chain; and on 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.

In addition, 55 countries have committed to reducing their cooling emissions under the Paris Agreement, either in their revised Nationally Determined Contributions (NDCs) or their long-term climate plans; this is up from only 6 countries that included cooling in their NDCs in 2015 (Clean Cooling Collaborative 2021; Cool Coalition 2021).

The role of cold-chains in food systems has also been recognized by the international community with the Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction through Sustainable Cold-chain Development and the UNEA 4 Resolution (Box 6 and 7).

Box 7. The Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction

At the Thirty-First Meeting of the Parties to the Montreal Protocol in Rome, the Government of Italy promulgated the Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction through Sustainable Cold-chain Development. The 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" (UNEP 2019). The Declaration aims to highlight the role of the cold-chain in implementing the UN's 2030 Agenda for Sustainable Development and achieving the SDGs related to ending hunger and poverty, food security, improved nutrition, climate action, sustainable agriculture and fisheries, and health and well-being. By signing the Declaration, states and other stakeholders, including the private sector, pledge their commitment to work on delivering sustainable cold-chains in cooperation and coordination with other governments, private and public institutions and all relevant partners.

4.2 TECHNOLOGY SOLUTIONS

Cold-chain is a logistics, transport and overall organizational challenge. The digital economy has made it vastly more efficient, with impacts on business models, service standards, financing, production and technology. However, barriers to market uptake of sustainable cooling solutions remain, especially in developing countries, due to issues such as lack of standards, infrastructure, reliable energy, financial capacity and local skills to develop and deploy such technologies. As a result, the cooling industry has been slow to innovate solutions that fit with the local context in these countries and scale up rapidly (Box 8).

The opportunity is that developing countries are not so encumbered by outdated intermediate technologies as developed countries and should aim to leapfrog to more advanced sustainable solutions whenever 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 GWP refrigerants, while delivering short-term interventions to reduce cooling loads, the energy requirements of equipment and the GWP of refrigerants in their markets.

Close coordination with experts at a global level will be required 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 in developing countries. For example, the Africa Centre of Excellence for Sustainable Cooling and Cold-Chain aims to accelerate the uptake of sustainable cold-chain solutions in the agriculture and health sectors to empower farmers, increase export revenues, enhance job creation, reduce climate and environment impacts, and foster low-carbon development (Box 9).

For developed countries, while they have access to the latest technologies* (Boxes 10 and 11), there is still no clear understanding as to what cold-chains will look like in the future. Developing a road map requires understanding how each of the diverse drivers will shape cold-chain provision over the coming decades to identify the most cost-effective transition pathway to a smarter, decarbonized and resilient cold-chain system, with reduced investment risk.

Box 8. Impagro Farming Solutions: A systems approach

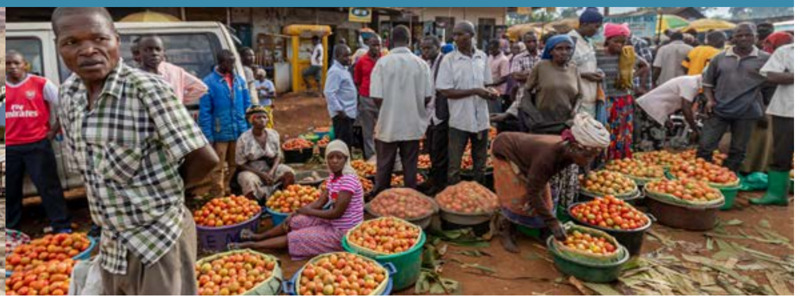
Impagro Farming Solutions takes a systems approach to understand the hurdles that prevent the mass adoption and use of decentralized cold-chain technology by farmers, cooperatives, producer organizations and agribusinesses. The aim is to use the framework to develop sustainable business models to operate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

BEFORE	DURING	BEFORE
• Cluster Development • Real-time Crop Data • Value Addition	• Asset Management • Spare Parts & Maintenance • After Sales Support	• Inventory Management • Embedded Logistics • Embedded Finance

* Cases mentioned are examples and not an exhaustive list.

Box 9. The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES)

The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES) was established in 2020 as a collaboration among government, academia, industry, communities and non-governmental organizations. The aim is to accelerate the marketing of sustainable solutions to simultaneously address the challenges of food loss and access to sustainable cold-chain and cooling. A key goal is to deliver 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 business models and financing mechanisms, 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.



Box 10. Daikin Europe N.V.: Demonstration of innovative integrated HVACR installations with natural refrigerant

Daikin is researching the potential of developing a Conveni-Pack* refrigeration, cooling and heating unit that uses CO_2 as a natural refrigerant. The company is evaluating mitigation options to ensure the safety of the unit and to enhance its energy performance, which is a typical challenge of using CO_2, especially in warm climates. At the core of this project, Daikin aims to demonstrate the feasibility and the sufficient maturity of heating, ventilation, air conditioning and refrigeration (HVACR) technology that uses CO_2 instead of the fluorinated R410A, which is to be phased down towards 2030.

* Daikin's Conveni-Pack is a commercial unit that combines refrigeration, comfort cooling and heating. Current Conveni-Pack system runs on R-410A refrigerant. See https://www.daikin.co.uk/en_gb/product-group/refrigeration/conveni-pack.html.

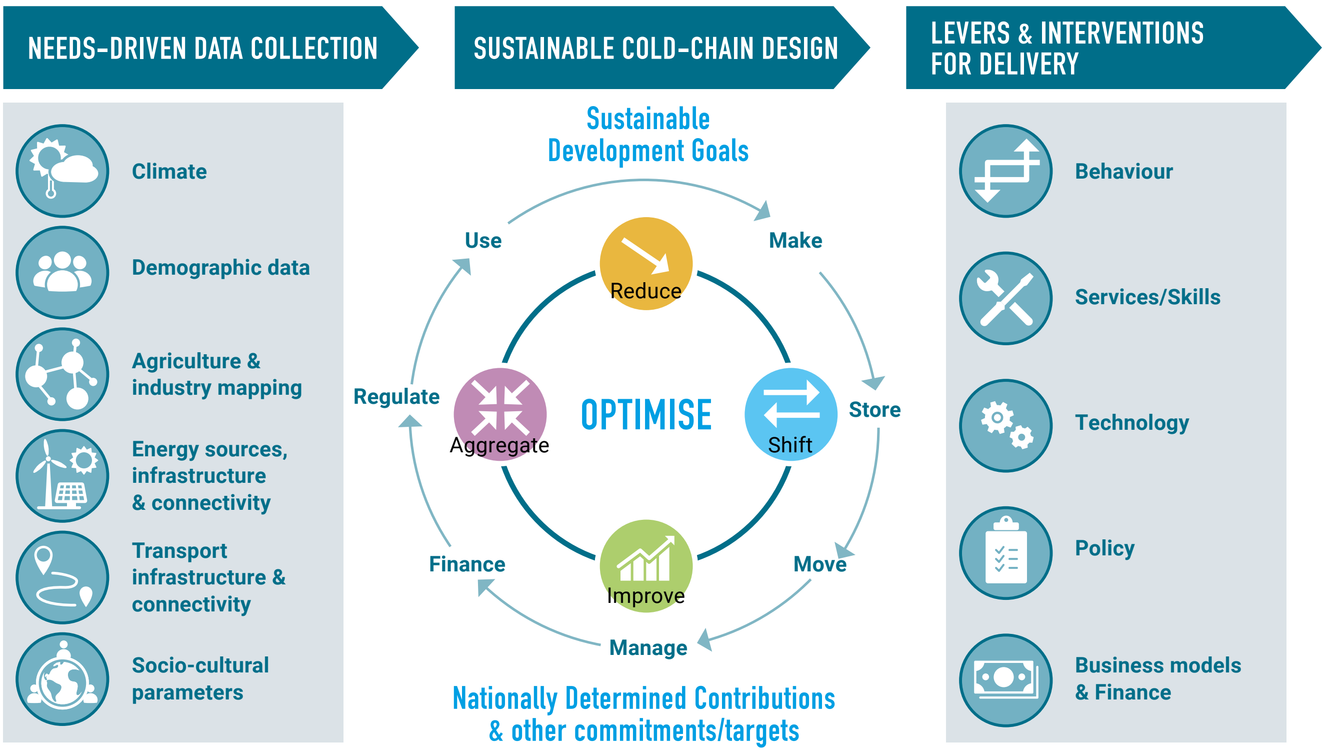
Box 11. ASDA: "Trial not error"

The UK supermarket group ASDA is exploring the opportunities and risks of achieving net zero emissions by 2040. To this end, WAVE Refrigeration has assessed the greenhouse gas emissions and capital and operating expenditures of different refrigeration technologies being trialled by ASDA. The assessment revealed that ASDA's strategic direction of adopting HFO (hydrofluoro-olefin) refrigerants results in the lowest annual emissions of all technologies considered. The technologies considered include systems using CO_2 which is a high-pressure refrigerant and resulted in inefficiencies that increase energy consumption when compared to HFO systems. From the net-zero emissions perspective, ASDA will need to capture or offset the direct emissions from HFO refrigerants. In this regard, CO_2 refrigerant systems are attractive alternatives. But ASDA from their studies say that they currently come with a higher CAPEX as well as OPEX with higher energy and maintenance costs compared to HFO systems for their applications.

4.3 SUSTAINABLE COLD-CHAIN DESIGN

Sustainable cold-chain design starts with assessing the end-to-end cold-chain needs along with climatic, demographic, and socioeconomic statistics; infrastructure; industry mapping, and an audit of existing and emerging technologies as well as policies, goals, targets, commitments and initiatives. It requires new thinking in key areas around how to use make, store, move, manage, finance and regulate cold to meet the current and future demand through the cold-chain, and to determine areas of intervention considering available energy and thermal resources, emission targets, and other commitments as well as costs. The optimum mix of fit-for-market solutions can be delivered through a "reduce-shift-improve" approach, supporting both early wins and the deep systemic changes that are essential to a sustainable cold-chain system (Figure 5).

Figure 5: **Systems approach to sustainable cold-chain design**



Developing a sustainable food cold-chain is a multi-dimensional, multi-sectoral challenge. It requires tackling the interdependencies that exist among economic, environmental, energy, technological, social, and political systems, as well as designing and implementing policies to address them. 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.

Overall, there is an urgent need to facilitate cooperation among governments in the developed and developing worlds, the private sector and academia; to incentivize and accelerate innovation and market transformation through policy actions; to support innovations of technologies and business models via public and private finance (Boxes 12 and 13); and to raise awareness of cooling issues among governments, businesses and end users of cold-chain. There is also an urgent need to develop the skilled workforce required to facilitate the deployment, operation and maintenance of new technologies in developing countries (as well as to protect against counterfeit refrigerants and components). In the developed world, dynamic capacity-building of the servicing sector and related skills are need to meet rapidly advancing sustainable cooling technology and business requirements.

Box 12. The Basel Agency for Sustainable Energy (BASE): Cooling-as-a-Service

The Basel Agency for Sustainable Energy (BASE) has helped initiate the concept of Cooling-as-a-Service (CaaS), 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 investment priorities) by allowing customers to pay for the service consumed on a fixed-fee-per-unit basis. Meanwhile, the ownership of the system remains with the technology provider, who is responsible for the service, maintenance of the system along with all operating costs. Hence, providers are incentivized to improve their energy efficiency to increase their profit margins.

Box 13. ColdHubs: Solar-powered walk-in cold rooms

ColdHubs Ltd. operates solar-powered walk-in cold rooms at farm clusters, produce aggregation centres and outdoor food markets in Nigeria. 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. Users pay only 100 Nigerian naira ($0.26) to store one returnable plastic crate per day inside the cold room – a unique pay-as-you-store Cooling-as-a-Service concept. ColdHubs currently serve 5,250 farmers, retailers and wholesalers using 54 cold rooms at 38 farms, aggregation centres and markets.

5 KEY RECOMMENDATIONS

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 on the cooling system – on individual technologies and integrated installations, such as supermarket refrigeration systems with waste heat recovery. But while cooling is a necessary service, it alone is not sufficient to make an efficient cold-chain. A holistic systems approach – from the point of harvest to the point of consumption – requires thinking beyond cooling technologies to meet the long-term challenge of delivering cooling and cold-chain services in line with achieving broader climate and other development targets.

A holistic approach demands reviewing the system-wide outcomes of the cold supply chain to protect the quality and nutritional value of the food. It also requires evaluating the energy loads and the total environmental impact by breaking down each primary supply chain activity along the cold-chain – including not just the cooling service, but also components such as packaging, sorting and grading, and mobility, all of which require attention from an energy and resource use perspective.

Food cold-chain solutions cannot achieve their maximum impact and efficiency without a systems approach that tackles the barriers to success in the most effective and efficient manner, and also integrates clean energy uses and market access, and other value-adding services.

Activities that can be part of such an approach include:

- Understanding and quantifying the 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.
- Understanding the current technologies and refrigerants that are in use or easily available.
- Effectively minimizing demand for climate-unfriendly cooling through the integration of passive cooling and alternate techniques, as well as promoting behavioural change.
- Making better use of available natural, "free" 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 through market expansion and the associated higher economic returns.
- Understanding how cold-chain drives gainful productivity from depleting agricultural (land, freshwater, sea) resources, as well as quantifying the value of such gains.
- Conducting a sectoral risk-benefit analysis of the 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.

Undertake a cold-chain needs assessment, develop a comprehensive National Action Plan, to provide the underlying direction for holistic and sustainable cold-chain and cooling infrastructure creation and rationalize cold-chain programmes across ministries.

For example, governments, development institutions and non-governmental organizations can use the Cooling for All needs assessment, developed by Heriot-Watt University and Sustainable Energy for All, to assess the full spectrum of cooling **needs** across buildings, cities, agriculture and health – as well as 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. Building on the needs assessment, countries can then develop National Cooling Action Plans, using the comprehensive methodology for NCAP developed by the Cool Coalition and its partners as a key policy tool to coordinate energy efficiency and the phase-down of HFCs in the cooling sector, and to proactively address their growing cooling needs while reducing the climate impact of cooling practices, improving access to cooling, and addressing several SDGs. NCAP's also help countries create the framework for cross ministry and multi-stakeholder collaboration required to achieve a holistic and sustainable cold-chain.

Develop five-year plans, missions, policies and dedicated agencies/departments, and provide financial assistance and capacity support for all required cold-chain components, with the aim to bring mobility in cold-chain and achieve seamless movement of agricultural produce from farm to fork.

This can include creating road maps 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 the cooling demand, enhanced energy performance standards and universal access to sustainable cooling. In India, schemes such as the Godown Scheme, the Mission for Integrated Development of Horticulture and Pradhan Mantri Kisan Sampada Yojana have been initiated to close the gap in food cold-chain infrastructure.

Build necessary skills and capacity as well as finance and business models in developing countries to support industry's engagement and technology deployment at scale.

Developed and developing countries must follow different pathways to achieve a sustainable food cold-chain system. The food diets of countries also have a direct impact on the type and capacity of cold-chains that a region will develop.

Developed countries have the capacity and resources to improve their food cold-chain in response to the urgent need to decarbonize their economies by deploying more advanced and environmentally friendly technologies. This process can be accelerated and eased if coordinated across regions. 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.

Some developing countries may continue to use conventional 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. However, this can result in a technological lock-in, with serious environmental, social and economic consequences in the long run, especially in the absence of technology and knowledge transfer from the developed world.

To engage industry in closing the technology and development gap, developing countries must build the necessary skills and capacity to adopt, operate and maintain new technologies that the industry is ready to offer. This will help create a better-prepared market for absorbing these technologies, ultimately enabling countries to leapfrog to advanced sustainable solutions and to 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 and overcome perceived issues around affordability and viability. Training is also necessary for identifying genuine refrigerants from counterfeit ones.

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 the 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.

Run large-scale system demonstrators to show the impact and how the interventions can work together to create sustainable and resilient solutions for scaling.

Large-scale system demonstrators 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.

Quantify and value the broader socioeconomic impacts of sustainable cold-chains such as income, economic growth, health, etc.

Quantifying and valuing these impacts would increase the scope of return on investment and improve the business case. This would allow 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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STATUS OF THE GLOBAL FOOD COLD-CHAIN: SUMMARY BRIEFING

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