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COLD-CHAINS IN DEVELOPING ECONOMIES

A TECHNO-SOCIO-ECONOMIC STRUCTURAL DEVELOPMENT CHALLENGE

BACKGROUND PAPER

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DISCLAIMER

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EXECUTIVE SUMMARY

Sustainable and clean cold chains are vital in developing countries and rural communities, if we are to achieve the Sustainable Development goals (SDGs) by 2030. A cold chain is not a stand-alone solution. It is an integrated, optimized, and managed network of temperature-environment controlled packhouses, vehicles, cold stores, and distribution hubs to ensure safety, quality and quantity of food. Currently at least 25% of food produce in developing countries is lost due to lack of cold chain.

It is estimated that the world will need to produce 56% more food in 2050 than in 2010 to feed the world.[1] Globally, about one third of all food produced is lost or wasted each year while 820 million people are malnourished.[2] Food loss and waste results in a financial loss of about $940 billion and an environmental impact of 4.4 GT CO2e.[3,4,5]

Of the total CO2e impact of post-harvest food loss, the lack or inefficiency of cold chain [6] accounts for approximately 1 gigatons of CO2e.[7] In addition, it is estimated that 600 million people worldwide fall ill every year and 420 000 die from contaminated food, in part due to a lack of cold chain.[8] However, cold chain systems typically use high-GWP (Global Warming Potential) refrigerants and fossil-fuels, through grid electricity, off-grid diesel-based generation and transport. The urgent challenge is to reduce food loss and waste by expanding cold-chain capacity quickly and affordably, while minimizing emissions.

Moreover, refrigeration alone cannot stop food loss, food in a refrigerated warehouse will still perish unless it relates to consumers. Connecting farmers' and fishers' produce with consumers may reduce food loss and positively impact smallholder producers by opening connectivity to new markets and increasing income opportunities. Reducing food loss is necessary to cope with the growing population and climate change.

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[1] WRI. 2019. "World Resources Report: Creating A Sustainable Food Future".

[2] FAO. 2011. "Global Food Losses and Food Waste – Extent, Causes and Prevention".

[3] FAO. 2014. "Food Wastage Footprint: Full-cost Accounting. Final Report".

[4] FAO. 2017. "Save Food for a Better Climate: Converting the food loss and waste challenge into climate action".

[5] The greenhouse gas emissions associated with this food loss and waste come from a variety of sources, including on-farm agriculture emissions; wasted electricity and heat used to manufacture and process the food; energy used to transport, store and cook food that is eventually lost or wasted; landfill emissions from decaying food, and emissions from land-use change and deforestation are all associated with producing food that is ultimately lost or wasted.

[6] A food cold-chain is the integrated set of activities undertaken to ensure that perishable food products are kept at the optimum temperature in the supply chain that stretches from harvested products to the end consumer.

[7] Global Food Cold Chain Council. 2015. "Assessing the Potential of the cold chain sector to reduce GHG emissions through food loss and waste reduction".

[8] WHO. 2019. "Food Safety".

The commitments under the Montreal Protocol including the Kigali Amendment and the Rome Declaration on the Contribution of the Montreal Protocol to Food Loss Reduction through Sustainable Cold Chain Management can support the mobilization of countries to leapfrog to sustainable cold chains.

The benefits of cold chain

Cold-chain services provide a diverse set of benefits including those for reducing poverty, achieving food security, building sustainable and resilient infrastructure, and promoting sustainable patterns of production and consumption. Cold chain services may benefit all the 17 SDG’s in some way, but in particular:

SDG 1 (No Poverty): cold chains are an integral part of reducing food loss, which may increase profits and incomes of producers. Working with local institutions to tailor cold chains based on local needs can increase the resilience of rural communities.

SDG 2 (Zero Hunger): reducing food loss can increase the availability of affordable food. Increased cold chain infrastructure can also create climate resilience within rural food supplies. It also allows farmers and growers to transition from growing crops of staples to producing higher value, perishable, micronutrient-rich foods, such as fresh fruits, vegetables, and animal-sourced products we need for healthy diets.

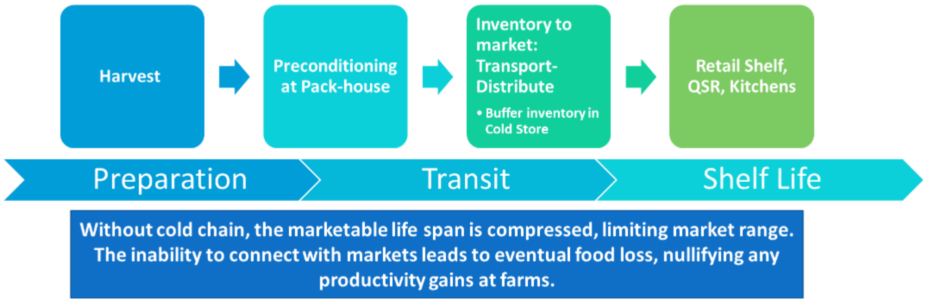
SDG 3 (Good Health & Wellbeing): improved cold chain infrastructure can extend food lifespans, reducing the number of people falling ill or dying from eating contaminated food. Furthermore, there is potential to integrate vaccine cold chains alongside food cold chains which may contribute to reducing the amount of liquid vaccines lost each year (25%).

SDG 8 (Decent Work & Economic Growth): cold chains can connect local clusters of farmers, growers, and fishers with higher-value local, national, and international markets. The market connectivity afforded by cold chain incentivises farmers to raise their outputs because they will earn more from what they produce. Cold chains also have the potential to allow higher value to move downstream to rural communities, creating jobs and broader economic growth, especially within rural communities.

SDG 9 (Industry, Innovation & Infrastructure): the cold chain is an interlinked set of sustainable and resilient infrastructure. Sustainable cold chain necessitates creating novel, sustainable technologies, improving the efficiency of existing appliances and facilitates further industrialisation.

SDG 12 (Responsible Consumption & Production): cold chains have the potential to incorporate circular economy ideas and business models with innovations that create cooling out of waste and recovered waste heat. In addition, cold chains are vital to reducing food loss and waste.

The stages of the cold chain



For a majority of agricultural or seafood products, the cold chain can be categorised into six stages:

Harvesting: deterioration of the products' integrity occurs from the moment of harvest. A positive step can be to harvest at the coolest time of day and use shading after the harvest.

Preconditioning: the preparatory phase for onward connectivity to markets. Products need to be cooled to an optimum temperature, sorted and packed. While waiting for onward transport, products have to be kept in refrigerated storage. Many products are cooked and processed, then chilled or frozen prior to onward transport.

Transport: various modes of transport form the critical process that interconnects all stages of a cold chain.

Bulk storage: as products arrive in bulk at warehouse storage (sometimes multiple stages), refrigeration is also required. These stages also buffer the inventory against demand and provide platforms to deconsolidate and undertake last mile delivery. Storage at various temperature levels is required to suit the type of food product.

Retail: refrigeration in equipment at merchandising end is required to keep products in a low-temperature environment before purchase by the consumer, both while in temporary storage and on display.

Domestic and Foodservice: products that require refrigeration should be stored in a refrigerator or freezer until consumed at home or, for food service establishments, cooked and served to customers. This also depends on consumer buying cycles and local supply chain.

Climate change impact of cold chain

Current cold-chain practices have a significant climate change impact. There are two different climate impacts caused by cold chain refrigeration equipment:

Direct Emissions (refrigerants) The food supply cold chain accounts for more than 20% of global HFC usage. [9] Keeping products cold throughout the mobile portion of the cold-chain (such as while in transit on trucks, trains and ships) represents about 3% to 7% of global HFC consumption, because of high refrigerant leakage and poor end-of-life disposal, contributing as much as 4% to the total GHG emissions of transporting all freight (refrigerated or not) [10]

Indirect emissions (energy) The global cooling demand for food, producer to consumer, is also energy-intensive at more than 1,000 terawatt hours (TWh) annually (including domestic refrigeration) and accounts annually for a gigatons of $CO2_e$ emissions (direct and indirect) globally.[11] If the world were to reduce food loss without intervention, energy demand from cold-chain (excluding retail and domestic) and food processing could add 1200 TWh of energy demand and more than 1.8GTs of CO2e (direct and indirect) annually. The number of transport refrigeration vehicles would need to triple to more than 11.5 million. [12]keeping food cold can account for 20% of the total vehicle's fuel. [13]

Understanding the amount of cold chain needed

There needs to be significantly more data from needs-based assessment methodologies outlining the cooling needs and requirements for differing countries and communities. WRI estimates that we will need to produce 56% more food in 2050 than we did in 2010. [14] However, without efficient physical connectivity, production cannot and does not translate into supply. A well organized and sustainable food logistics network is critical to supply the production, with minimum product losses to feed the projected 10 billion people nu 2050. Both the WRI and EAT-Lancet studies set targets for reducing food loss and food waste by 50% and cold-chains are an essential enabling technology to meet the target.[15]

However, we are yet to quantify what would be required to meet these targets or the

[9] Fay, K. 2015. "Study Highlights Importance of Food Cold Chain in Reducing Food Waste GHG Emissions".

[10] Global Food Cold Chain Council. 2015. "Assessing the Potential of the cold chain sector to reduce GHG emissions through food loss and waste reduction".

[11] University of Birmingham. https://www.clean-cooling.ac.uk/

[12] Ibid.

[13] Tassou, S. A.; De-Lille, G.; Ge, Y. T. 2009. "Food transport refrigeration - approaches to reduce energy consumption and environmental impacts of road transport."

[14] WRI. 2019. "World Resources Report: Creating A Sustainable Food Future".

[15] https://wrr-food.wri.org/; https://www.thelancet.com/commissions/EAT

transport, storage and distribution required for nearly 6 billion tonnes of food by 2050, a substantial portion of which will be fresh and temperature sensitive produce. We need to understand the physical numbers and capacity of temperature-controlled road vehicles, cargo ships, multi-modal containers, domestic refrigerators, chilled display cabinets, cold storages, pack houses, ripening chambers, pre-coolers and a plethora of other cold chain supporting equipment and infrastructure in the energy, transport, retail and food logistics sectors. Currently, less than 10% of temperature-sensitive perishable foods have access to cold chain systems worldwide and many developing countries have a negligible cold-chain capacity underscoring the definitive need for action on cold chains to meet food security and nutrition targets by 2050. [16]

Trade-off with reducing food loss

Cold chain offset some of the CO2e emissions related to food loss. However, without intervention to deliver sustainable, low-GWP and energy efficient cold-chain, the emissions that would be added will be significant, and the net benefit could be a small overall reduction. In fact, according to one academic study, increased CO2e from an unsustainable (traditional) cold chain would outweigh the CO2e savings from the reduced food loss. [17] In addition to the phase down of HFCs, the Kigali Amendment has created opportunities to enhance energy efficiency in the cooling sector. Full utilization of the opportunities is essential to ensure that climate benefits resulting from the Amendment are maximized.

Challenges to sustainable cold chain

In most developing countries there is limited or even negligible cold storage equipment/ refrigerated transport, from harvest to retail point. Where there is equipment, it is often old, or obsolete, from industrialized markets, and the focus is often on moving food for export. Previous interventions have mainly focused on increasing productivity as opposed to market connectivity. Key challenges include:

Financial capacity of marginal and small farmers: farmers do not have access finance for purchasing equipment and supporting post-harvest product storage.

Organization: there is a lack of collaboration among stakeholders for collective action and investments.

Awareness, skills and education: farmers lack awareness of simple techniques to take care of produce post-harvest, and training on the usage of sophisticated cold-chain equipment.

[16] GIZ. 2016. “Promoting Food Security and Safety via Cold Chains”.

[17] Heard, B. R.; Miller, S. A. 2019. “Potential Changes in Greenhouse Gas Emissions from Refrigerated Supply Chain Introduction in a Developing Food System”.

Lack of integrated demonstrations: there are no large-scale cold-chain demonstrations to showcase its efficacy and impacts.

Lack of "First Mile" infrastructure: there is inadequate agricultural infrastructure or inappropriate vehicles to transport the produce from the farm-gate to the pack-house.

Risk of technology lock-in: conventional cooling technologies are being deployed instead of highest energy-efficient or emerging clean-cooling technologies feasible. If the climate impact of cold-chain is not addressed, the cold-chain will grow, but will depend on and locked into incumbent technologies, such as diesel generators. There is also an active market in the second hand, less efficient equipment, which, although more affordable to consumers in developing countries, has higher polluting impacts and risk technology lock-in.

Lack of necessary infrastructure in rural areas: cold chains require robust transport and energy infrastructure to be in place to operate reliably with seamless market connectivity. One study in India reported that a typical driver would need to stop 49 times during his 2,400km journey because of bad roads and also toll-gates which operate on different billing systems.[18]

Lack of drivers for change and attention to cold chain components beyond large-scale storage: public sector's attention in developing economies remains focused on the provision of large-scale cold storage rather than encouraging the building of integrated cold chains for market connectivity.

Non-affordability of E-mobility: both electrical transportation fleets and on-board battery for cold production can be expensive to purchase and maintain. Additionally, there is a lack of charging infrastructure to support electric transportation and associated transport refrigeration.

Immediate solutions available to assist the transition to sustainable cold chain

Assistive zero-energy systems such as low-cost vegetable storage using evaporative cooling at the farm where climate allows.

Building design: thermally efficient, well-insulated building with passive cooling approaches. (insulation is equally important for vehicles).

Best-in-class equipment: most refrigeration systems will last 14-20 years; therefore, it is essential that as new systems are deployed in developing markets, they are of the highest energy

[18] Pednekar, R. 2015. "Challenges in Implementing Compliant Cold Chain in Emerging Markets: Case Study India".

efficiency, such as variable speed compressors, and lowest GWP refrigerants feasible, and with good control systems.

Maintenance: refrigerant leakage rates are high, significant direct emissions and increased energy consumption can be avoided with better maintenance practices.

There is also the potential to increase overall system efficiency by a breadth of interventions, from reducing demand to system integration to harnessing waste heat for co-located processes and using thermal storage for time-of-use and demand management and resilience in the event of power failures. As shown below a range of interventions could be used.

Examples of Indirect Emission Reduction Opportunities

Intervention Area	***Example***
Behavior Change	*Ensuring optimum or acceptable temperature settings*
Demand Mitigation	*Using natural shading, good building design, natural ventilation*
	Improving insulation, etc.
Efficiency improvements	*Improving the efficiency of existing appliances, control systems*
	Using thermal storage for time of use management
	Recovering waste heat into co-located service e.g. hot water for cleaning and washing applications in pack-houses
Demand Aggregation	*e.g. Community cooling hubs*
Natural Energy Resources	*Using evaporative cooling, sky cooling, river or deep water*
	Using low grade geothermal to drive sorption chillers
Waste Energy Resources	*Making use of waste industrial or commercial heat and waste cold using different technologies*
System Intervention	*Making modal shifts (road to rail or even road to drones)*
	Tri-generation, thermal networks

What could an energy-efficient optimized packhouse system look like using an integrated approach

Overall system design needs to consider:

1. Environmentally friendly location close to sustainable modes of transport
2. Clean energy sources for transportation
3. Thermally efficient, well-insulated building with passive cooling approaches and sustainable cooling technologies
4. Minimum, convenient and efficient movement of humans and materials
5. Optimization of the use of energy and water
6. Low GWP refrigerants
7. Disposal of waste
8. Lifecycle Analysis of building structure, materials and equipment for most moderate environmental impact.

The way forward

Now – *the right foundations*

Robust 'cooling for all' needs assessments to drive holistic system planning for socio-economic and climate impacts.

Develop the in-country strategies to support the adoption of sustainable cold-chains with smart technology, effective policy, accessible business models and impactful financial assistance.

Initiate end-to end demonstrations to educate policy makers, investors, business, users and consumers.

Medium-term

Build-out cold chain infrastructure as a seamless and resilient end to end delivery system using sustainable technology and business practices throughout and ensuring maximum value flows back to-small and marginal farmers, their families and rural communities.

Build out the knowledge base and skills capacity to support and maintain the cold-chain.

Goal

Comprehensive cold-chain and all inclusive rural multi-service community cooling networks such that there is demand aggregation and reverse synergetic traffic across the system to deliver optimum efficiencies and sustainable value chains in line with the UN SDGs, the Paris Agreement and Kigali Agreement.

Optimum, sustainable and climate-friendly cooling and cold chain can only be introduced if the entire system is designed cohesively and with an integrated systems approach from the outset rather than piecemeal technology deployments which solve singular aspects of the problem but ignore the end outcomes and bigger picture goals.

The development of sustainable refrigeration and cold chain is not only about switching to low-GWP refrigerants but also giving due consideration to energy efficiency, shifting to renewable energy, and optimizing the need for cooling. It will require holistic delivery strategies to include policy, creative and collaborative models for finance and business, training for both technical and business skills, and live end-to-end demonstrations for relevant stakeholders.

Large scale advocacy on the benefits of sustainable cold chains will be vital. The change will need to be driven by knowledge partners with expertise in cold chain, logistics, business, finance and policy, and multi-lateral donors and financiers and by political will.

The Kigali Amendment gives cold-chain operators a clear incentive to install low-GWP or zero-GWP refrigerants. There is an opportunity to leapfrog from no cold-chain to refrigeration and cold-chain strategies that advance business and environmental goals. Including ensuring high efficiency, safe, low-GWP systems are installed now which are still fit for purpose in ten years' time into the future; preventing refrigerant leakage through maintenance and planning for decommissioning and end-of-life disposal.

More strategic approaches could allow pack-houses and cold-chain businesses to expand their services and create sustainable community cooling hubs, make use of renewable power, or develop new revenue streams by providing waste heat or excess cold to district services, while further supporting the Paris Climate Agreement; the Montreal Protocol and its Kigali Amendment; and the SDG's.

Detailed information on technology options for cooling solutions that include information on costs and emissions impacts can facilitate cost benefit analysis by policy makers and operators whilst developing their own cold-chain plans. Novel business models such as the provision of "cold" as a service using Farmer Producer Organizations, farmers' associations or other service providers may be considered within such plans.

With access to robust information, advice and support, including financing, farmers, producers and cold-chain operators can make informed and rational choices on sustainable cold chain development. A strong public-private knowledge-partnership may drive successful change, as shown, for example, by India's National Centre for Cold-chain Development.

However, unintended consequences must be considered related to increased cold chains, raising awareness to potential issues. For example, increased consumption of processed foods, increased food waste from storage and increased income inequality between farmers and fishermen. These consequences can also bring benefits. For example, increased gender inequality with rising agricultural revenues, reduced deforestation and land degradation due to less food waste.

Key recommendations

Some crucial recommendations we suggest, to expand upon the Kigali

Amendment and ensure sustainable cold chain implementation are:

- Help bring the cooling and cold-chain challenge to the forefront of conversations and shape energy and monetary policies in ways that support the future cold-chain needs and thus the needs of the world.
- Develop clear consensus roadmaps for sustainable refrigeration, not just low GWP refrigerants, to guide long-term strategy with objectives, interventions, and timelines.
- Develop a detailed technology option list (IT platform) to include costs and emissions impacts for cooling solutions that can facilitate cost benefit analysis by operators and policy makers of options whilst developing their own cold-chain plans.
- Shift current unsustainable cooling technologies to resilient renewable technologies.
- Create novel business models such as Cold as a Service using FPOs or other service providers.
- Drive collaboration between all actors within the cold-chain, including flow of information (demand forecasts) from the retailer or processor to farm and digital supply chain tools to make transactions in the supply chain more efficient and seamless, enable the tracking of loss and waste, and even allow for dynamic chains.
- Provide incentives and financing structures to support end-users in leapfrogging to low climate-impact solutions.
- Adopt protocols to stop the developing markets being the dumping ground for low efficiency or end-of-life high polluting equipment.
- Create Centers of Excellence and Model cold-chains (Living Labs) to demonstrate end-to-end systems - not only technologies but also the socio, business, governance, policy and funding models - so that farmers, producers and cold-chain operators can make informed and rational choices based on robust, comparative performance information and have access to advice and support.
- Using India's National Centre for Cold-chain Development as an example of public-private knowledge-partnership to drive change.

ACRONYM LIST

Acronym	Description
AC	Air-Conditioning
Bn	Billion
CaaS	Cooling as a Service
CCDP	Crop Cluster Development Program
CO_2	Carbon Dioxide
DFI	Doubling Farmer's Income
EE	Energy Efficiency
ESCO	Energy Service Company
EU	European Union
FAO	Food and Agriculture Organization
FPC	Farmer Producer Companies
FPO	Farmer Producer Organisations
GCCA	Global Cold-Chain Alliance
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographical Information System
Global LEAP	Global Lighting and Energy Access Partnership
GOI	Government of India
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
IDAF	Integrated Development of Artisanal Fisheries
kg	Kilogram
Km	Kilometer
kWh	Kilowatt Hour
LNG	Liquefied Natural Gas
LOIs	Letter of Intent
MoU	Memorandum of Understanding
MT	Metric Ton
NCAP	National Cooling Action Plan
NCCD	National Centre for Cold Chain Development
NCCD	National Centre for Cold-chain Development
O&M	Operation and Maintenance
ODS	Ozone-Depleting Substances
OGCCC	Off-Grid Cold-chain Challenge
PCM	Phase-change Materials
PHL	Postharvest loss
PV	Photovoltaic
QSRs	Quick Serving Restaurants
R&D	Research and Development
Rs	Rupees
SDGs	Sustainable Development Goals
SFACH	Small Farmer’s Agri-Business Consortium of Haryana
SWOT	Strength, Weakness, Opportunity, and Threats
TEAP	Technology and Economic Assessment Panel
TWh	Terawatt-hour
UAE	United Arab Emirates
UK	United Kingdom
UN	United Nations
USA	United States of America
VLE	Village-level Entrepreneurs
ZECC	Zero Energy Cooling Chamber

GLOSSARY

Cold Chain: a temperature-controlled supply chain, consisting of a sequence of refrigerated production, storage, and distribution activities, along with associated equipment and logistics.

Cooling as a Service (CaaS): customers paying for the cooling on an ‘as use’ basis, with a third party funding the capital, infrastructure and maintenance costs and selling a cooling service.

Food loss, food waste, and food wastage are terms related to the food supply chain. Food loss is the unintended reduction in food available for human consumption, resulting from inefficiencies in supply chains. Food waste refers to discarding or alternative (non-food) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer level. Food wastage encompasses both food loss and food waste.

Montreal Protocol: An international agreement, finalized in 1987, to protect the ozone layer by phasing out ozone-depleting substances such as HCFCs. The Kigali Amendment to the Montreal Protocol is a commitment to cut the production and consumption of HFCs by over 80% over 30 years.

Sustainable Cooling: cooling without climate impact, in line with the objectives of the Paris Agreement on Climate Change, even as the demand for cooling increases. Measures that reduce the demand for artificial cooling (e.g. insulation, building design) are included in this definition.

Sustainable Development Goals: introduced in 2015, is a set of 17 universally agreed “Global Goals”, with a combined total of 169 indicators.

The Paris Agreement: a legally binding global climate agreement adopted by 195 countries in December 2015 and entered into force in November 2016. It aims to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius.

INTRODUCTION

Historically the environmental focus of the refrigeration and air-conditioning sector has been on ozone-science associated with the need to reduce the impact of refrigerants on the atmosphere. The Montreal Protocol aimed to phase out ozone-depleting substances (ODS) including hydrochlorofluorocarbons (HCFC) refrigerants. More recently the Kigali Amendment to the Protocol added the phasing down hydrofluorocarbons (HFCs) in response to their high Global Warming Potential (GWP) greenhouse gas (GHG) emissions. [19]

There is a growing recognition that the demand for cooling is projected to grow significantly and the indirect emissions from the electricity generation required to power cooling technologies is four times greater than the direct emissions from the refrigerants themselves. [20,21,22] These two dynamics create a significant threat to our ability to achieve the targets defined in the Paris Agreement on limiting climate change. Therefore, it is essential that both the direct and indirect emissions associated with the cooling provision are addressed. In line with this, the United Nations (UN's) Technology and Economic Assessment Panel (TEAP) review on transitioning to climate-friendly alternative refrigerants resulted in a broader sustainable cooling agenda.[23]

A cold chain is not, as many perceive it, the provision of cold storage alone. It is an integrated, optimized and managed network of temperature-environment controlled pre-conditioning, pack houses, vehicles, cold stores, and distribution hubs which seamlessly maintains custody of the food under care, to assure the safely, quality and quantity of food, and to deliver it swiftly from farm, harbor or beach to consumption centers across geographies and over time. Currently at least 25% of food produce in developing countries, and often half of some temperature-sensitive produce, is lost because of lack of cold-chain.[24] Approached correctly – suitably localized with market focused, purpose-driven business and finance models underpinned by socio-economic-political governance and policy frameworks - cold-chains are

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[19] The chlorine in HCFCs are both ozone-depleting substances and greenhouse gases. Because HFCs have no chlorine, bromine, or iodine, they are not ozone-depleting substances. However, like other halocarbons, they are potent greenhouse gases.

[20] Potentially at a rate of 18 cooling devices – such as domestic and industrial refrigerators, room air-conditioners, mobile air-conditioners etc. – being sold on average every second to 2050.

[21] 20% refrigerant – direct emissions; 80% electricity generation – indirect emissions.

[22] UNEP TEAP, 2017a

[23] The TEAP initiative is limited to technology rather than a broader range of energy efficiency opportunities

[24] Alongside food losses due to lack of cold-chain, the World Health Organization estimates that nearly 25% of liquid vaccines are wasted each year primarily because of broken cold-chains. An estimated 1.5 million people die each year from vaccine-preventable diseases. This will be discussed in the rural cooling section.

an essential contributor to a nation's economic development and central to achieving the delivery of our shared global Sustainable Development and Climate Change Goals. [25]

Cold-chains can connect local clusters of farmers, growers and fishers with higher-value local, national, and international markets while simultaneously building the sustainable and resilient food supply system we need to feed 10 bn people. The market connectivity afforded by a cold-chain enables and incentivizes farmers to raise their output because they will earn more from what they produce; whereas its absence often means that any effort to increase yield will be largely offset by higher volumes of wastage - so dousing the incentive to invest. Importantly, cold-chains allow farmers and growers to transition from growing crops of staples to producing the higher value, perishable, micronutrient rich foods, such as fresh fruits, vegetables and animal sourced products we need for healthy diets, increasing their earning potential and improving the economics of the rural community in which they work while simultaneously opening up adaptation options in response to a changing climate.

However, despite the clear and well-understood socio-economic benefits to be gained from cold-chain usage, only about 10% of temperature-sensitive perishable foods are refrigerated worldwide and many developing countries have negligible cold-chain capacity, or indeed no cold-chain deployments in place. The challenge is how to expand cold-chain capacity quickly and affordably in these countries, delivering societal and economic impact while ensuring minimal pollution and environmental impact – in other words to implement sustainable cold-chains rather than simply deploying the world's traditional 'business as usual' cold chain. Whereas cold-chain will likely happen organically in developing countries driven by consumer demand from a growing middle-class, specific intervention is required to ensure that it is delivered in a sustainable way, including economically empowering small and margin farmers and protecting the environment.

This paper aims to provides a comprehensive review of the complex issues associated with current and future cold-chain deployments in developing economies, as well as practical, grounded thought-leadership on potential solution pathways and interventions for impact. As such it is a ground-breaking contribution to the quest for sustainable development.

[25] Please refer to annex 1 for a list of connections between cooling and the SDGs

DEMAND, ENERGY AND EMISSIONS

If we are to deliver universal access to cooling for all (both urban and rural populations) by 2050, we will need to deploy 14 bn cooling devices globally. [26,27] Using conventional fossil fuel-powered equipment, 'universal access' to cooling would consume more than 19,000 terawatt-hour (TWh) of electricity. [28] To manage cooling for all within the constraints of limiting global warming to 2°C and the projected renewable electricity capacity, the energy demand of cooling equipment will need to be reduced by 70%.

In 2018, the global cold-chain market was valued at about $203 bn and is projected to reach about $293 bn by 2023.[29] Under the University of Birmingham and Flexible Power Systems convergence modeling scenario, energy consumption to provide cooling for cold chain will grow by 130% between now and 2050 this includes industrial refrigeration, which is predominantly for food processing.[30,31,32,33,34]

The mobile cold-chain accounts for 7% of global HFC consumption. This contributes to 4% of the total global warming impact of moving all freight (refrigerated or not).[35] Furthermore, diesel-powered transportation refrigeration units consume up to 21% more than a non-refrigerated diesel-powered truck, and the CO_2 impact from energy alone increased more than five times.[36] In terms of the total climate impact, South Africa in 2016, for example, had 14,000 refrigerated trucks and trailers which emitted 2M T CO_2e. This is projected to increase to 5M

[26] Birmingham Energy Institute and The Institute for Global Innovation. n/d. "A Cool World: Defining the Energy Conundrum of Cooling for All" [Available]: https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/2018-clean-cold-report.pdf

[27] As opposed to 9.5bn devices if we simply aim to meet demand projections based on anticipated growth in GDP and population (currently there are 3.5bn devices in use, and these are mainly domestic fridges and room air-conditioners).

[28] Double the 9500TWh projected under the mainstream GDP and population growth-based scenario.

[29] Markets and Markets.2018. "Cold-chain Market" [Available]: https://www.marketsandmarkets.com/PressReleases/cold-chain.asp

[30] Convergence models have an embedded assumption that the new cold chains will be at least as efficient as those of the developed world as they are rolled out.

[31] International Institute of Refrigeration, 5th Informatory Note on Refrigeration and Food.

[32] Within Stationary Refrigeration: 0.2407 pieces of industrial refrigeration equipment per thousand inhabitants and 14.09 pieces of commercial refrigeration equipment per thousand inhabitants. Within Mobile Cooling: 1.29 pieces of transport refrigeration equipment per thousand inhabitants.

[33] It is important to note that these numbers do not include the motive energy nor the refrigerant, merely the energy consumption of the mobile cooling unit.

[34] Refer to appendix 1 for full list of data

[35] Greenbiz.2013. "How Coke, UTC are cooling the cold-chain's climate impact" Blog [Available]: https://www.greenbiz.com/blog/2013/10/18/how-coke-utc-are-cooling-cold-chains-climate-impact

[36] ADEME.2012."Comité de gouvernance de la base d'impacts ACV pour l'afficahge'" Presentation [Available]: https://slideplayer.fr/slide/1313063/

T CO_2e by 2020.[37] Additionally, there are about 1.1 million reefers in use globally. The fleet consists of about 1 million 40-foot units and 100,000 20-foot reefers.[38]

AGRICULTURAL COLD-CHAINS

THE DEVELOPMENT CONTEXT

Agricultural cold chains role as an enabler of economic growth and nutrition must be viewed in the context.[39] Currently, more than 1.1 bn people do not have access to cooling, many of whom reside in rural areas, and suffer the consequences daily, including malnutrition from the inadequate food supply, poverty, constrained productivity and health impacts.[40] Globally, 800 million people are malnourished, and more children die each year from malnutrition than from AIDS, malaria and tuberculosis combined.[41] It is estimated we need to produce 56% more food in 2050 than we did in 2010 to feed the world.[42] In addition, about 600 million people – almost 1 in 10 worldwide – fall ill every year after eating contaminated food, around 420,000 of whom die.[43] Agriculture is also an important sector for employment in developing countries. For example, 50% of the workforce in India is directly employed by agriculture, 73% in Rwanda and 40% of the total population in Kenya.[44]

Connecting the supply of highly nutritious foods to vulnerable populations requires cold chains to ensure that fresh produce of excellent quality reaches them. However, only about 10% of temperature-sensitive foods are refrigerated worldwide, contributing to post-harvest food loss.[45] Some studies have shown post-harvest food losses in some developing economy markets to be as high as 80%. The Near East and North Africa region of Africa loses 55% of

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[37] GIZ and DTI of South Africa. 2016. “Mitigating emissions in the transport refrigeration sector in South Africa” [Available]: https://www.giz.de/de/downloads/160712_TRP_Facht_Sheet.pdf

[38] Cermak, R., Kauffeld, M., Konig, H., Lawton, R., Pachai, A.C., Rusignuolo, G. 2014. “Report of The Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee”

[39] Refer to annex 2 for cold chain logistics in developing economies

[40] SEforALL. 2018. “Chilling Prospects” [Available]: https://www.seforall.org/sites/default/files/SEforALL_CoolingForAll-Report.pdf

[41] UN Standing Committee on Nutrition

[42] FAO. 2019. “Key facts on food loss and waste”

[43] WHO (2015)

[44] OECD.2016. “Evolving Agricultural Policies and Markets: Implications for Multilateral Trade Reform”

[45] Refer to appendix 2 for fruits and vegetables temperature requirements

horticultural produce. [46,47] About 1.3 billion tons of crops produced annually, enough to feed approximately 1.6 billion people, are not consumed.[48,49]

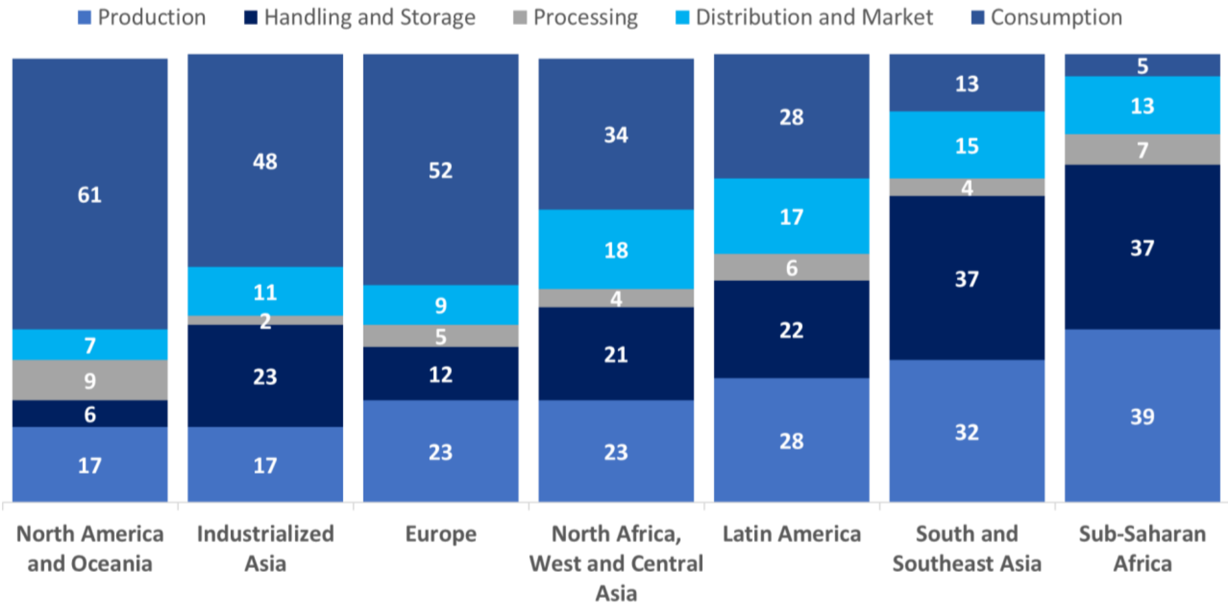

FIGURE 1: FOOD LOST OR WASTED BY REGION AND STAGE IN VALUE CHAIN (PERCENT OF KCAL LOST AND WASTED)

As shown in figure 1, 39 % and 32% of KCAL produced is lost or wasted at the production stage in Sub-Saharan Africa and Southeast Asia respectively. An additional 37 % of the KCAL produced in the two regions are lost during handling and storage.[50] However, there has been little progress on post-harvest losses globally.[51] This may be attributed to the fact that 95% of agricultural research investments in sub-Saharan Africa over the last 30 years have been directed to increasing productivity, with only 5% aimed at reducing food losses.[52] A lack of cold chain contributes to losses of fruits and vegetables (55%), meats (22%), and dairy (20%) in the region.

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[46] FAO.n/d. "Developing the Cold-chain for Agriculture in the Near East and North Africa (NENA)" ***Policy Brief*** [Available]: http://www.fao.org/3/a-ax746e.pdf

[47] Kitinoja,L.,Saran,S., Roy,S.K., Kader,A.A.2011. "Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy" [Available]:https://www.ncbi.nlm.nih.gov/pubmed/21302312

[48] Deloitte.2015. "Reducing Food Loss along the African agricultural value chains". [Available]: https://www2.deloitte.com/content/dam/Deloitte/za/Documents/consumer-business/ZA_FL1_ReducingFoodLossAlongAfricanAgriculturalValueChains.pdf

[49] This is based on an assumed daily caloric intake of 2,500 per person and total food wasted of 1.5 quadrillion kilocalories

[50] WRI analysis based on FAO. 2011. Global food losses and food waste—extent, causes and prevention. Rome: UN FAO.

[51] InspiraFarms. 2018. "What's New: Launching Our Asset Finance Credit Facility 2.0" ***News Story*** [Available]: http://www.inspirafarms.com/launching-our-new-asset-finance-credit-facility/#_ftn1

[52] https://documents.wfp.org/stellent/groups/public/documents/special_initiatives/WFP265205.pdf

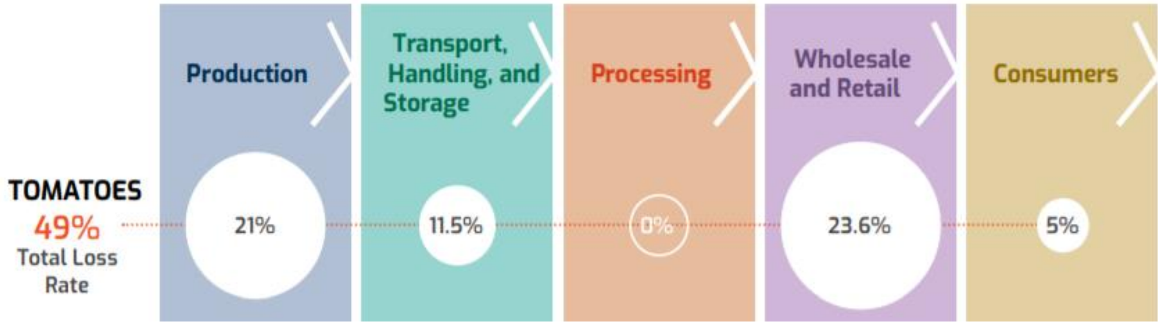

FIGURE 2: TOMATO LOSS AND WASTE HOTSPOTS ALONG THE VALUE CHAIN IN RWANDA (LOSS PERCENTAGES OCCUR AT EACH STAGE)

Rwanda produces 97,400 tons of tomatoes, of which 49% is lost in the value chain. A lack of cold chains is one of the key reasons for tomato losses. Currently there is no cold storage available at the farm or market stages of the value chain. As of today, only 5% of firms in the food and agriculture sector have refrigerated trucks, while 9% have a cold room to store fresh produce.[53] The lack of cold chain causes the pulp temperature to be anywhere from 7-15˚C higher than the ideal temperature at the farm, wholesale market, and retail market stages. This translates into a shelf life of 1-3 days instead of 1-3 weeks under ideal temperature conditions.

CASE BOX 1: TOMATOES LOSS AND WASTE IN RWANDA[54]

Alongside reducing food losses and providing enough nutritious food, a focus on sustainable development requires that cold-chain interventions simultaneously improve the livelihoods of the roughly half a billion small and marginal farmers and their families.[55]

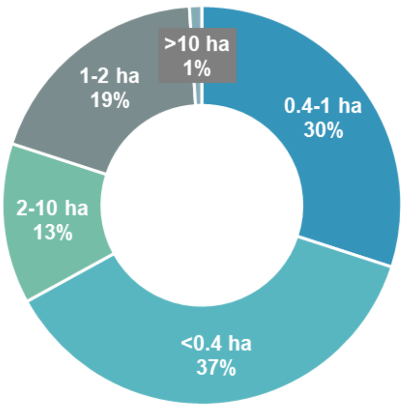

FIGURE 3: THE SIZE OF INDIA'S FARMS

[53] Van Dijk, N., Y. Dijkxhoorn, S. van Mewrriënboer. SMART Tomato Supply Chain analysis for Rwanda. Identifying opportunities for minimizing food losses. BoP Innovation Center, Wageningen University and TNO, SMASH program. http://www.bopinc.org/sites/www.bopinc.org/files/updates/smart_report_0.pdf

[54] Based off WB FLW team country diagnostics

[55] Christen,R.P. and Anderson,J. 2013."Segmentation of Smallholder Households: Meeting the Range of Financial Needs in Agricultural Families"

Of these farms, more than 200 million are located in the developing economies of South and Southeast Asia, approximately 50 million in sub-Saharan Africa and approximately 12 million in Latin America.[56] There are 118 million small and marginal farmers in India, 85% of the 139 million landholdings (see figure 3). Currently, small, and medium farms supply more than 50% of the essential nutrients in the global food supply.[57]

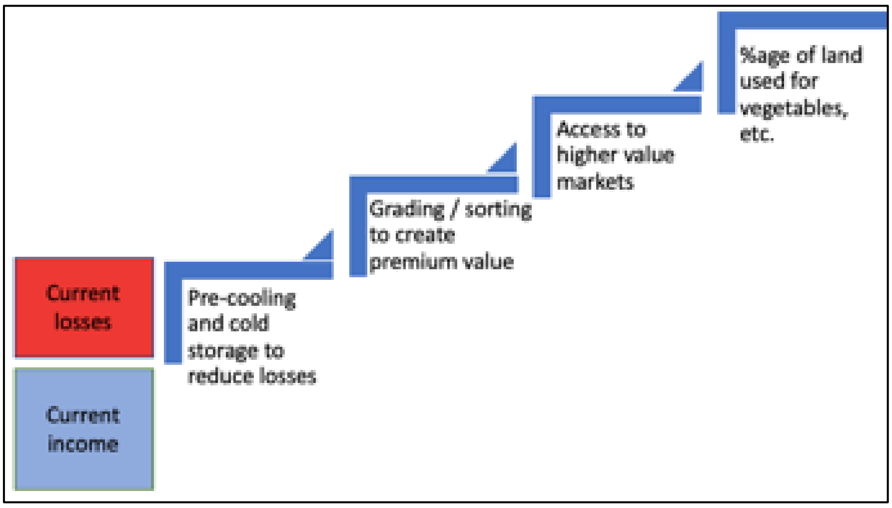

FIGURE 4: HOW CAN COLD-CHAIN INCREASE FARMERS' INCOMES

The deployment of cold-chain also allows these farmers, and the producer co-operatives they establish, to earn more by maintaining the quality of their produce and providing the efficient and effective connectivity needed for selling it further.[58] According to the National Centre for Cold Chain Development (NCCD), in India, farmers can often see a more than 5x increase in value by moving product directly to distance markets. Beyond the immediate opportunity cold chains provide for enhanced income from food sales in distant markets, the deployment of cold-chain capacity may empower farmers by unlocking the potential to grow different types of produce.

Beyond the immediate opportunity cold chains provide for enhanced income from food sales in distant markets, the deployment of cold-chain capacity is empowering for farmers in that it can also unlock the potential for growing different types of produce. This not only enables previously unreachable higher value markets to be accessed but also adaptation to new growing conditions as they emerge in a world of, changing climates. Essentially, besides

[56] FAO. 2014."What do we really know about the number and distribution of farms and family farms in the world?" ***FAO ESA Working Paper No. 14-02*** [Available]: http://www.fao.org/3/a-i3729e.pdf

[57] Thornton, P.K., et al. 2017. "Farming and the geography of nutrient production for human use: a transdisciplinary analysis"

[58] Currently, selling small volumes of their produce in distress sales through intermediate partners/local traders in local markets can lose them up to 75% of the total net margin accruing to the entire supply chain. https://pdfs.semanticscholar.org/6bd3/796d46faab2b3c000a873894844ccd6104b0.pdf

improving economic gains through safe and expanded market connectivity, cold chains help with building capacity for the future resilience of farmers and the rural communities in which they are located. And in employment terms, as an example, 49% of the workforce in India is directly employed by agriculture, 63% in Bangladesh, 66% in Nepal and Rwanda and overall the sector accounts for 57.4% of total employment in sub-Saharan Africa and 42.2% in Southern Asia.

Additionally, with global population growth, of which the majority will be in Africa to 2050, and the related rise of African cities and urbanization, with youth and young urban professionals needing easy access to convenience meals and quick service food outlets, more diverse products, and higher quality foods in the home and at the restaurant and hotel, cold-chains will play a critical role. Producers will need better access to aggregation, cleaning and cold-storage and cold-logistics, as well as chilling and rapid freezing capabilities for added value food processing that will result in further economic development opportunities for rural communities, thereby extending their agricultural sector activities into the broader, higher-value agri-food business (and as stated earlier, by 2050, 68% of the world's population will live in urban areas dependent on 'farm to fork' connectivity).

Cold chains can assist in making better use of natural resources by reducing loss of food between field and fork; create jobs and economic growth, especially within rural communities; and benefit supporting industries such as transportation and export. However, unless appropriately designed to minimise cooling demand and use non-fossil-fuel, low GWP refrigerant technologies, growth in cold-chain will create undesirable pollution and degrading energy exploitation. To do so, several challenges and barriers need to be overcome.

THE CHALLENGES AND BARRIERS OF THE AGRICULTURAL COLD CHAIN [59]

(I) THE SCALE OF THE INFRASTRUCTURE NEEDED

There are numerous studies which estimate that we would need to produce more food, that we need to reduce food loss and waste and that we need a dietary shift to a healthy, nutritious, sustainable, predominantly plant-based diet. However, most of these studies do not try to quantify what would actually be needed to successfully meet these targets or how to move nearly 6 bn tonnes of food needed to feed nearly 10 bn people by 2050, a substantial portion

[59] Refer to annex 4 for related cold chain developments, stories and business models.

of which diet will be fresh and temperature-sensitive produce.[60] Even where such assessment has been undertaken, such as India's NCAP, demand is based on projections of GDP, population growth and urbanization without consideration for the nutritional security of the population. Furthermore, with urbanization expected to grow rapidly over the next two decades, the challenge of moving the anticipated volumes of nutritious perishable produce required from farm gate to urban forks will be significant.

As to an indication of the size of the challenge, currently more than 90% of fresh perishable food in the UK passes through a cold-chain at some point on route at the consumer's table from the point of production, whereas by comparison in India barely 10% of the produce that could benefit from using a cold-chain actually does so61 - The UK has 10x more refrigeration transport vehicles than India alone, yet India's population is 12x larger. India is the world's second-largest producer of vegetables and fruit and among the top ten in fish and meat but the bulk of these perishable products face risk due to inadequate handling and logistical support. Reportedly, in India upwards of 25%[62] of such produce is lost due to a lack of farm-gate preconditioning, refrigerated vehicles and shipping containers and other supply chain bottlenecks.

Cold chains require robust transport and energy infrastructure to be in place to operate reliably with seamless market connectivity. Large-scale investment is needed in many developing countries to improve the road, rail, shipping, and energy provision at a basic level. A report by the Asian Development Bank in 2009 estimated that between 2010 and 2020, approximated $8 trillion is needed in overall national infrastructure investment in member countries, with $4.1 trillion in energy and $2.5 trillion in transport infrastructure.[63]

(II) THE ENERGY AND ENVIRONMENTAL IMPACTS

The addition of a substantial amount of energy-consuming equipment and infrastructure to enable the movement of 56% more food produced globally will also have significant

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[60] What would be needed in terms of a physical increase in the number of temperature-controlled road vehicles, cargo ships, rail freight wagons, domestic refrigerators, chilled display cabinets, cold storage facilities, pack houses, ripening chambers, pre-coolers and a plethora of other cold-chain supporting equipment and infrastructure in the energy, transport, retail and food logistics sectors.

[61] In India, where cold-chain infrastructure is in place, it is often designed solely for the storage of potatoes.

[62] In some studies (GIZ) food losses of fruit and vegetables across the entire value chain from producers to consumers in India are reported as currently amounting to about 40% of the production. A key driver for these high food losses is the lack of appropriate cold-chain infrastructure.

[63] ADB. 2017. "Asia Infrastructure Needs Exceed $1.7 Trillion Per Year, Double Previous Estimates" ***News Story*** [Available]: https://www.adb.org/news/asia-infrastructure-needs-exceed-17-trillion-year-double-previous-estimates

environmental impacts if achieved using today's fossil fuel-powered technologies.[64] The global cold-chain is already energy-intensive (>1,250TWhs annually) and accounts for ~1.2 gigatons of CO_2e globally (more than aviation or maritime combined). Without appropriate intervention, cold chain energy demand could increase by 130% to 2.6 TWhs by 2050.[65] Unplanned, ill-informed investment in the cold-chain sector can create a carbon-intensive stand-alone infrastructure of cold storages, reefer vehicles and ripening chambers instead of a sustainable, integrated and cohesive agri-food supply chain system.

Given the use of refrigerants and insulation in cold chains, the sector is also essential for the Montreal Protocol and Kigali Amendment. According to the Global Food Cold-chain Council, the food supply cold-chain currently accounts for about 20% of global HFC usage.[66] Keeping products cold throughout the mobile portion of the cold-chain alone represents 7% of global HFC consumption, contributing as much as 4% to the total global warming impact of moving all freight (refrigerated or not).[67]

(III) LACK OF INNOVATION IN SMALL SCALE, SUSTAINABLE AND AFFORDABLE TECHNOLOGY

Currently, cooling more generally secures less than 0.22% of the annual European Union (EU) engineering research budget; thermally the focus is on heat. With limited research investment or policy support, the development and deployment of new clean cooling and sustainable cold-chain technologies in mature developed economies, where most of the research and development (R&D) is undertaken, has been slow.

Government policies, schemes and interventions in developing economies are not designed to drive innovation in, or the adoption of, 'clean' sustainable cold-chains. Subsequently, they are more likely to increase energy demand and GHG emissions through the addition of conventional cold-chain infrastructure. Almost all current incentivization efforts associated with cold chains in developing countries are focused on adding infrastructure and cooling capacity based on 'business as usual', rather than emerging non-fossil fuel powered 'clean' cooling technology. The adoption of such infrastructure could lead to GHG emissions that negate the

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[64] Refer to annex for an overview of technology and development

[65] See appendix 1 for more detail

[66] Cooling Post. 2015. "Refrigeration Can Reduce GHG Emissions." ***News Story*** [Available]: https://www.coolingpost.com/world-news/refrigeration-can-reduce-ghg-emissions/.

[67] Global Food Cold-chain Council

savings in CO_2e realized from reducing post-harvest food loss and indeed exceed those savings by up to 10%.

(IV) LACK OF AWARENESS, SKILLS AND EDUCATION

There is often a lack of education and awareness among farmers about simple rudimentary techniques for post-harvest care of produce, such as proper packing, let alone on the usage of sophisticated cold-chain equipment. Making the best use of pre-cooling, transport refrigeration and cold store equipment requires knowledge of setpoint temperatures and how to manage the respiration of certain products. This knowledge capacity and associated skill set needs to be built up from zero in communities with no, or limited, access to mechanical cooling technologies. This barrier makes cold-chain equipment useless without proper training and operation and maintenance (O&M) support. At the same time, culturally in some countries, refrigerated produce is viewed negatively by farmers and consumers in local markets, in that it is not seen as 'fresh', and seen as the method of last resort for food that is already in the process of rotting.

(V) LACK OF/POOR PRIORITIZATION

In developing economies, most cold-chain technologies deployed in developing countries are located in urban centers and major transport terminals – such as ports and airports – where produce exporters are typically based. This does not help with reducing food losses in the transportation of produce from farm to the consumption point or solve the critical stage of removing field heat from freshly harvested crops.[68]

Moreover, government attention in developing economies has been overly focused on the provision of large-scale cold storage rather than encouraging the building of integrated cold chains for market connectivity. Current infrastructure development remains focused on creating large-scale cold storage units, in an average of 100,000m^3 capacity.[69] For example, the Global Lighting and Energy Access Partnership (Global LEAP) "Off-Grid Cold-chain Challenge" (OGCCC) is an international 'cold-chain' competition yet it's objective is to identify and promote the most energy-efficient, sustainable, and cost-effective technologies that can

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[68] National Research Council. 1978. "Postharvest Food Losses in Developing Countries"

[69] GCCA. 2018. "Global Cold Storage Capacity Report" [Available]: https://www.gcca.org/sites/default/files/2018%20GCCA%20Cold%20Storage%20Capacity%20Report%20final.pdf

meet a cold-storage requirement. The competition does not focus on connectivity or multiple stages, and many of the business models associated with the proposed solutions are designed to sell pieces of cold store equipment costing $20,000 – 40,000 to farmers.

(VI) LIMITED FIRST MILE SOLUTIONS

The "first-mile" is the stage of food produce transportation that links farmers to the nearest rural road or a product collection point. In smallholder farming, this is complicated by the fact the production is spread across numerous farms over a vast spatial territory; the distance of the first-mile can range from 0.25 km to 200 km. Field studies show that most food loss occurs at the first mile, in the flow of produce from the farm gate to a local aggregator.[70] First-mile transport in a developing country usually involves sub-optimal handling of produce, which results in damages to crops and ultimately lost value.[71] Produce is frequently transported in fibre sacs that lack ventilation and often faces long exposure to sun and rain. There are frequently delays in carrying from the farm-gate or consolidation points, which makes matters worse.

Low-cost solutions for collection points, such as roadside sheds, can function as brief produce stopovers, but they do not add significantly to shelf-life extension. Presently, cooling solutions at collection points are limited to containers retrofitted with expensive diesel-powered 'gensets.' Produce is stored here briefly before being taken to a pack-house or processing plant. Intermediate transport is often not refrigerated, creating an immediate break in the cold chain. Where there are transport services, these are often low quality and unreliable transport services and often monopolistic with high charges that can increase depending on the seasons.

Attention is focused on cold storage rather than the cold chain as a whole. Policymakers continue to an approach of incentivising cold-rooms, instead of supporting the transfer of goods from farm-gates to retailers. In several states in India, the current policy is to create large cold-rooms instead of locating smaller cold-rooms/pack-houses close to farm-gates, which would facilitate better use of storage. Even where the government has developed pack-houses, they have often not looked at solutions for first mile.

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70 Future Agenda.2019. "Food Waste." Blog [Available]: https://www.futureagenda.org/insight/food-waste

71 In developing economies, "First-mile" infrastructure may consist of the local village, along with farms paths and tracks that are inaccessible to most conventional transport vehicles. Typical modes of transport used in this portion of product movement are human porterage, animal carts, bicycles, and motorcycles. In some cases, tractors and pick-up trucks are also used. This process is usually time-consuming and costly - in terms of cost per km, "first-mile" is often the most expensive segment of the logistics process and can make up to 20% of the total transport costs

(VII) LACK OF ACCESS TO FINANCE

Credit provided by informal and formal financial institutions, as well as value chain actors, currently only meets an estimated $50 bn of the more than U$200 bn need for smallholder finance in the regions of sub-Saharan Africa, Latin America, and South and Southeast Asia. Fewer than 15% of farmers have access to a formal savings account.[72]

Cold chain infrastructure is a capital-intensive investment and access to low interest rate capital is vital for business profitability. Interest rates for loans on cooling equipment can be a multiple higher than for standard farming machinery as it is not categorized as agricultural equipment. Moreover, in countries where cold chains are under-developed or non-existent, loan officers have limited knowledge of the business viability of cold chain infrastructure and associated business models, making them reluctant to loan without substantial amounts of capital to small and medium farmers without guarantees for a sizable loan collateral/asset to de-risk their investment.[73] There is a vital need for a paradigm shift in how we finance sustainable cold chains.

(VIII) NEW BUSINESS MODELS NEEDED

Cold chains will only be taken up by small and marginal farmers and associated supply chain players if they are affordable within the local economic context. Furthermore, the mere presence of equipment or infrastructure is not sufficient. Appropriate business operating models, cold-chain management systems, training and skills development will be crucial to the sustainability of such interventions.

In developing economies, interventions are likely to require new business and funding models, such as “pay as you use” service-based innovations, driven through empowered Farmer Producer Organisations (FPOs), be they as Farmer Producer Companies (FPCs) or co-operatives. Equally key is to enable small and marginal farmers through FPOs and other knowledge transfer channels to understand how to avail services of the integrated components

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[72] Dalberg Global Development Advisors and the Initiative for Smallholder Finance. n/d. “Inflection Point: Unlocking growth in the era of farmer finance” [Available]: https://mastercardfdn.org/wp-content/uploads/2018/06/Inflection-Point_April-20160-accessible.pdf

[73] High-interest rates on loans needed for capital-intensive investments, often lead to farmers and logistics operators seeking assistance from development projects. While projects can, and often do, provide valuable sources of funding, there are conditions attached via deliverables and reporting that may detract, or at the very least distract, from the fundamental core business of managing cold-chain logistics.

of storage and transport to gain the economic advantages available from cross-geography access, distance-price arbitrage, time-arbitrage and cross-seasonal trading. This is where new value is created, and management is as important as the physical infrastructure required to enable the flow of food from the point of production to the end of consumption.

And where, in addition to FPCs and co-operatives, commercial actors such as local entrepreneurs, medium-sized farmers and third-party logistics companies are incentivised to become the local service providers, it is essential to ensure a fair and equitable flow of value back to the producers themselves.

(IX) LACK OF INTEGRATED SYSTEM TOOLS AND DEMONSTRATORS

Given the very different thermal and handling requirements of different products, the matching of technology to product and context is critical, but there also needs to be a broader understanding of how these technologies map together to provide an interconnected cold-chain while minimising overall carbon emissions, maximising value creation, and reducing waste. By adopting a whole system perspective, computer models can be used to evaluate scenarios and strategies that would be hard to capture at scale in the real world. Thinking in this way offers a radical approach to optimisation of the local, national, and even international food supply chain.

The Centre for Sustainable Road Freight (CfSRF) was formed six years ago and is a collaboration between three Universities (Cambridge, Westminster, and Heriot-Watt) and an industrial consortium. CfSRF has developed large scale data collection, processing, and analyzing approach for logistics data to support large modelling, simulation, and optimization of logistics systems. The modified living lab approach involves using prototype technology to develop inputs to a digital twin which can be used to scale operations and technology, thereby providing a platform for the evaluation of a future state that may be radically different to the current system. An essential application of this modified living lab approach has been to identify energy/CO2reduction pathways that integrate technology, information, operations and policy.

(X) LACK OF REGULATION AND FOOD SAFETY NORMS

Existing regulations are not enforced or are poorly executed. In many cases, the lack of enforcement is the result of a government struggling with limited resources. The sampling of food products is an essential step in monitoring food safety; however, opening refrigerated containers or trailers and leaving them open for extended periods compromises the integrity of the cold chain, leading to temperature fluctuations that damage the product. Additionally, where regulations do exist, they may be copied and pasted from another government or taken from an entirely different industry, leading to regulations that are unreasonable and unrealistic in the country's context. Food-safety practices written into regulations should be considered through the lens of industry best practices, and enforcement should follow accordingly.

(XI) LACK OF ABILITY TO MANAGE COLD-CHAIN COMPLEXITY

The diversity of the products transported, the various stages involved and the distances and routes they travel to market mean that cold-chain management is complex, requiring locational, product and context-specific temperature-environment control and sensitive, integrated, seamless handling of goods, i.e. no single solution to roll-out. Consequently, many complexities arise:

- Products that share the same optimum temperature range for storage and transport are not necessarily compatible for co-containment.[74]
- Many businesses providing logistical support are not organized businesses, which results in haphazard, poorly managed networks with inadequate quality control and an inability to handle the complexity of integrated cold-chain operations.
- There is a lack of space and infrastructure within retail stores leading to sub-optimal management and storing of produce.

(XII) DUMPING OF USED/LESS 'CLEAN' EQUIPMENT

There is evidence of leasing companies and manufacturers in industrialized countries 'dumping' old and less clean technologies in developing countries as regulation restrictions become tighter in industrialized jurisdictions. There is also an active market in the second hand, less efficient equipment, which although more affordable to consumers in developing countries has higher polluting impacts and risk technology lock-in.

[74] Refer to appendix 10, the table 'Shelf Life and Maintenance of Fruits and Vegetables' illustrates the range of variation that can lead to incompatibilities in the handling requirements of various fresh fruits and vegetables.

(XIII) E-MOBILITY

Both electrical transportation fleets and on-board battery for cold production can be expensive to purchase and maintain; and there is a lack of charging infrastructure should there be an effort to support electric transportation fleet.

INTERVENTIONS FOR IMPACT

(I) NEEDS ASSESSMENT

Despite being instrumental to achieving several of the SDGs, to-date, analysis and projections of cooling demand do not deliver access to cooling for the benefit of all who need it. Instead, projections have tended to be equipment estimates based on GDP and population growth and have not considered the scale of cooling and energy demand of a scenario that achieves access to sustainable cooling for all who need it. The implications this demand has for the energy systems, new-build generation requirements and the environment (climate change and pollution) or workforce are therefore poorly understood. An underestimation of the scale of the cooling demand and its impact on energy demand risks a lack of ambition in policy, infrastructure, and technology development, and could ultimately have far-reaching social, economic and environmental consequences. Alongside failing to capture needs, the focus on per capita equipment penetration rates pre-supposes a solution to specific cooling needs and risks ignoring the possibility of electricity demand mitigation by a redesign of systems, demand aggregation, modal shifts, and use of waste or currently untapped resources.

SEforALL has recently launched general needs assessment methodology and tool which focuses on the implications that cooling has on energy systems, climate change, health, wellbeing, and economics. [75] This is a good starting point, but it may need to be adapted to countries and development context. And it should be applied to each country and sector to gain an understanding of the multiple socio-economic-political benefits from sustainable cold-chain deployments, and appropriate 'fit-for-purpose' and 'fit-for-market' purpose-driven business models can be created.

[75] SEforALL. 2019. "Needs Assessment Tool". [Available]: https://www.seforall.org/cooling-for-all-needs-assessment

(II) SYSTEM INTEGRATION AND OPTIMIZATION

Given the very different thermal and handling requirements of different products, the matching of technology to product and context is critical, but there also needs to be a broader understanding of how these technologies map together to provide an interconnected cold-chain while minimising overall carbon emissions, maximising value creation, and minimising waste. By adopting a whole system perspective, computer models can be used to evaluate scenarios and strategies that would be hard to capture at scale in the real world. Thinking in this way offers a radical approach to optimisation of the local, national and even international food supply chain.

The Pack House: a system within a system

The packhouse must be viewed as a system within a system. All system design components need to be considered simultaneously in parallel with a circular economy approach. The

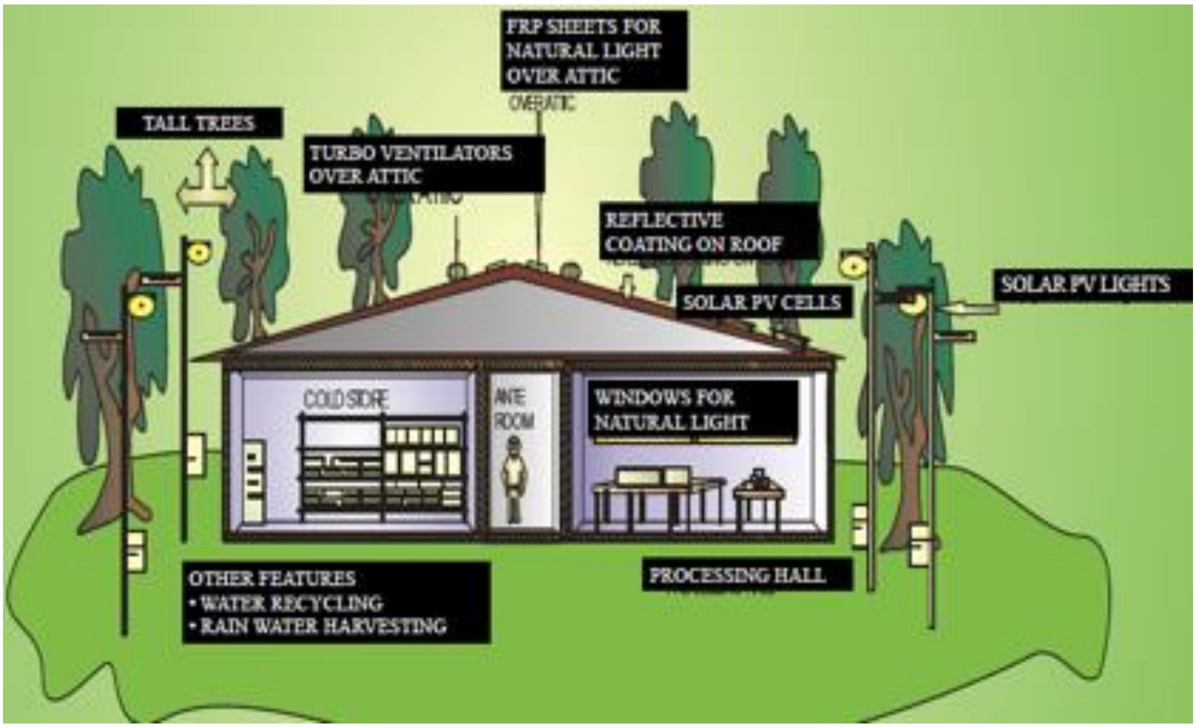

FIGURE 5: ILLUSTRATION OF A PACKHOUSE

refrigeration systems have to be based on environment friendly low GWP refrigerants, technical soundness, reliability and best possible energy efficiency. However, sustainable, and green design concepts can be introduced if the entire system is designed cohesively and with an integrated systems approach from the outset.

Overall system design needs to consider:

- Environmentally friendly location close to sustainable modes of transport
- Clean energy sources for transportation; including how to support e-mobility
- Thermally efficient, well-insulated building with passive cooling approaches and sustainable cooling technologies
- Minimum, convenient and efficient movement of humans and materials
- Optimization of the use of energy and water
- Low GWP refrigerants
- Disposal of waste
- Lifecycle Analysis of building structure, materials and equipment for most moderate environmental impact
- Affordability and socio-economic impacts and benefits
- Regulatory environment and incentives
- Business and finance models and trading platforms

(III) PURPOSE-DRIVEN BUSINESS MODELS

'Fit-for-purpose' models need to take an integrated entire system contextualized approach, which is both commercial and purpose-driven, and that explicitly takes different in-country stakeholders' perspectives into account on multidimensional aspects including *financial, environmental, technical, social and political*. Through this novel approach, an in-depth understanding of the socio-economic-political advantages of proposed and their implementation challenges can exploit real-world opportunities, thereby reducing investment and implementation risks.

"Pay-as-you-Cool" (Cold as a Service, CaaS)

Cooling as a Service (CaaS) is primarily a cold storage 'on-demand' model that focuses on small farmers and those based in the first mile of connectivity that requires cooling access but have limited purchasing capability. CaaS end-user customers pay for the cooling on an as-used basis, with a third party funding the capital, infrastructure, and operational and maintenance costs. The latter recover their costs through usage payments made by the customer.

CaaS models can benefit farmers by removing the economic burden of upfront capital investment. This provides small farmers with the opportunity to enter the cold chain without

INSPIRA FARMS

InspiraFarms has launched a business model similar to that adopted by ColdHubs. In the implementation of their model, InspiraFarms set cold stores near strategic production areas, for which an agreement is reached in advance with several users such as farmers' cooperatives or agribusinesses with numerous smallholder suppliers.

Each on-demand cold storage unit is designed around a minimum of 200 small-scale producers. Fees for the service are calculated according to the type of produce and the projected volumes to be stored. Numbers can be agreed either based on weight or number of crates to be stored, or even flat rates for long-term agreements considering each specific case. InspiraFarms will, in some cases, partner with the local business ecosystem (such as private 3rd party logistics providers and distributors) to scale up if additional capacity is required.

CASE BOX 2: INSPIRA FARMS

having to purchase the technology and infrastructure, but still being direct users of it. The model also reduces the perceived technology risk for these end-users, as they are not required to invest in a novel, innovative technologies directly, and are not exposed to equipment failure or maintenance demands. It can also incentivize technology providers to increase their profits by reducing their equipment's operating costs through energy efficiency innovation. And can also increase the likelihood that cooling systems are effectively serviced and maintained (and upgraded) by the third-party operator, lowering the risk of unplanned breakdowns and creeping inefficiency.

COLD HUBS

Founded in July 2015 by a farmer and entrepreneur Nnaemeka Ikegwuonu, as a social enterprise to alleviate some problems facing farmers in Nigeria, ColdHubs operates the pay-as-you-use modular, solar-powered (with battery back-up and for night-time), walk-in cold rooms for 24/7 off-grid storage of perishable foods. Each cold store can hold 3 tons of food, and the modular units are aggregated to increase capacity within any given location. The cold stores are installed in markets (the equipment does not provide pre-cooling for the removal of post-harvest field heat), and farmers can rent plastic crates and storage space on demand for a fee of $0.50. To socialize the market and educate farmers (and retailers) about the advantages of using refrigeration, as well as changing the way they access markets, ColdHubs provides illustrated booklets in local languages on post-harvest best practices and financial benefits and offers free trials of their cold stores.

ColdHubs are now expanding their market connectivity by developing refrigerated transportation service and thereby taking the first steps towards establishing an integrated sustainable cold-chain based on their business model crate of food. Each ColdHub typically has two female operators, and the company claims a utilization rate of 100% of capacity.

CASE BOX 3: COLD HUBS

Payments are typically set as a 'fixed-price-per-unit' tariff for the cooling service used (*e.g.* per ton of refrigeration, a cubic meter of cooled air, or as simple as cost per tray of food in a cold store overnight). The payment is not dependent on the savings accrued to the user (as with an Energy Services Company model) but instead agreed in advance of service access as a function of actual usage.

Finance Credit Facility – Asset Financing

In the agribusiness space, several technology companies are beginning to develop asset finance facilities as ways to enable their clients to acquire productive assets more efficiently. The advantage that asset finance gives over other means of funding is the ability to use the asset being purchased to serve as the collateral. InspiraFarms and Montpelier Foundation are using this model for cold storage and processing facilities. For example, the credit facility finances the acquisition of InspiraFarms's assets, such as on-farm cold storage and processing facilities, with terms and conditions that are tailored to the needs and capabilities of the agribusiness:

- Lends up to 80% of the total invoice value.
- Tenors of 12 to 36 months
- Instalment payments every six months
- Competitive interest rates of 10-12% per annum.

The six-month instalment schedule is designed to account for the seasonality of clients' cash flows, and a simple hire-purchase agreement is used to allow for the transfer of ownership once repayment is complete. Credit assessments include information on the value chain that the client operates in and cash flow projections for verifying the financial viability of the investment. These assessments help determine if a business will be able to effectively utilize the asset to benefit from the investment and meet the financing terms.

Franchise model with the medium-scale farmer or local entrepreneur as the hub of the eco-system

Impagro Farming Solutions is developing an innovative business model to multiply the incomes of India's smallholder farmers in a sustainable way. The franchise model works with medium-sized farmers and village-level entrepreneurs (VLEs) to establish and operate 'Impagro Hubs', which are ecosystems of the post-and pre-harvest activities designed not only to earn attractive returns for the owner/operator but also to drive up the profitability of local smallholder farmers. The service is intended to provide small-scale rural cooling hubs that can support the more extensive production areas and provide the support that can elevate small farmers to a new level of competitiveness and sustainability. Impagro's pilot project is in the Ratapani region of Madhya Pradesh, 70km from the state capital, Bhopal.

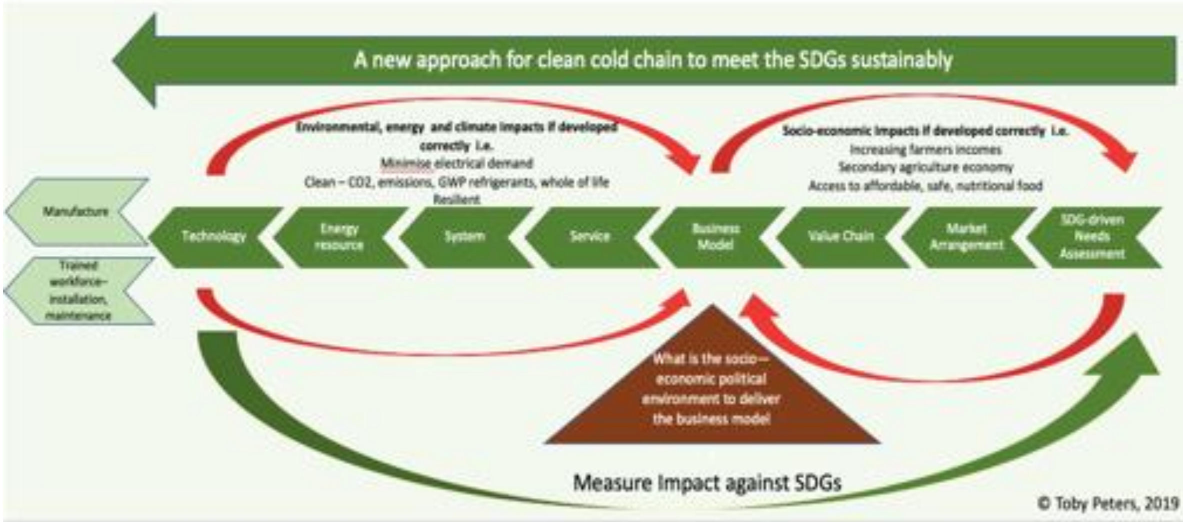

FIGURE 6: SCHEMATIC OF INTEGRATED PROCESSES FOR DEVELOPING A SUSTAINABLE FOOD COLD CHAIN BUSINESS MODEL

Within the development of the novel 'fit-for-purpose' business models, it is critical to recognize:

a) *Customer-centricity and market connectivity*

- ✓ Cold-chain interventions need a thorough understanding of the anchor customer and translate selective action into a comprehensive overall approach.
- ✓ For cold-chain interventions to make real sense, they must either connect from first-mile to existing cold storage infrastructure, which is typically situated in or around urban areas, or to last-mile and suitable markets (consumer or wholesale markets).
- ✓ In planning cold-chain interventions, where local markets do not allow for price premiums to be paid, alternative, more indirect marketing routes should be considered. Failure to do so can threaten economic viability.

b) *Fork to farm information*

- ✓ It is opportune to imagine a business structure that links market needs with harvesting and post-harvest storage and haulage: enabling and empowering farmers by facilitating the flow of knowledge and information; tracing the forward- and reverse-flow value of cold-chains from farm to fork and fork to farm – reducing food losses and bringing the value back to the farmers – working in the form of a block-chain technology; and increasing transparency in the supply chain.

A Methodology, not a single model

There needs to be the co-design of a flexible open-source methodology for the deployment of ‘fit-for-purpose’ and ‘fit-for-market’, *financeable,* end-to-end, clean and sustainable cold-chains that are attractive to end-users, civil society, governments, policymakers, industry and the finance community to ensure impact, lasting legacy and scalability. The methodology should recognize that the financial viability and longevity of the business model is key to influence.

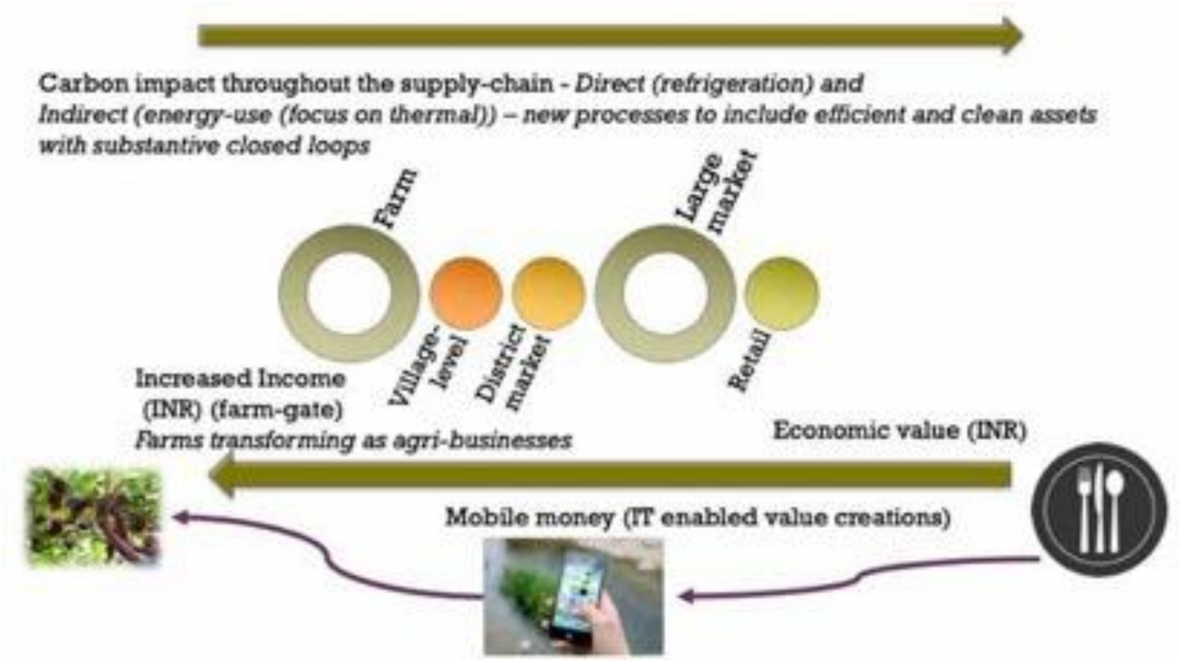

FIGURE 7: FARM TO FORK AND FORK TO FARM FLOWS

Critically this methodology must:

- ✓ not be prescriptive but enable rural communities to identify their specific food logistics cooling needs and the potential accretive impact of cold-chain for their community – such as a transition to higher-value crops, increased production, secondary agriculture;
- ✓ match “fit for market” bundles of low carbon technologies with appropriate revenue levels to deliver robust, clean end-to-end cold chains;
- ✓ share value and create an economically sustainable end-to-end system;
- ✓ define the funding requirements and financial (as well as social and environmental) benefits in such a way as to be in the best position to secure financing/business engagement;

- ✓ understand and enable the optimum governance, policy, regulatory, finance, procurement and on the ground in-country delivery mechanisms – for example, FPOs or businesses or potential community entrepreneurs (i.e. mid-sized farmers).

c) *Financing*

- ✓ The smallholder finance industry must move towards a future in which financial service providers engage closely with customers to design and offer appropriate, desirable products through integrated and innovative partnerships supported by more and smarter government incentives.
- ✓ A coordinated effort across actors will address today's most binding constraints: a gap between farmer need and demand for financial products, elusive business model returns for financial service providers, and a mismatch between capital needs and the type and volume of capital available from investors.
- ✓ Alternatives such as shared asset ownership, credit or hire purchase type models that are merged with Energy Service Company (ESCO) type arrangements, benefit-sharing, or government interventions financed by directed taxation should be explored in regard to the types of hardware (or service) being financed and the preferences of potential customers and vendors.
- ✓ Alternative financing approaches should be considered that facilitate community level through to international action, and this should include consideration of reallocation of some agricultural subsidies to support clean cold-chain development.
- ✓ The key to success will be working directly with the farmer/FPO to define viable business models anchored in relationships that will provide purchase contracts and guarantee a stable revenue stream.
- ✓ Finance for scale-up will need to be considered through realistic development pathways from 4 perspectives:
  - International – Public
  - International – Private
  - Domestic – Public
  - Domestic – Private

d) *Farmer Producer Organization - Cooling as a Service*

- Cold as a Service could be delivered through an FPO, farmer co-operatives (for cold chain) offering affordable, reliable 'pay per use' access. Users pay per unit of cooling, while the FPO owns the equipment, maintaining it, and paying the energy costs. Equally it allows aggregation of services or equipment to, for example, sell load-shifting services back to energy providers thereby improving the economic value for all stakeholder's energy generator, asset owner and service user.
- Where the CaaS model is commercially or privately deployed, it is important that the commercial model ensure value flows back to all stakeholders, including the end user rather than be exclusively captured by the asset owner; EcoZen, ColdHubs, InspiraFarms and Impagro Farms all reflect this goal.

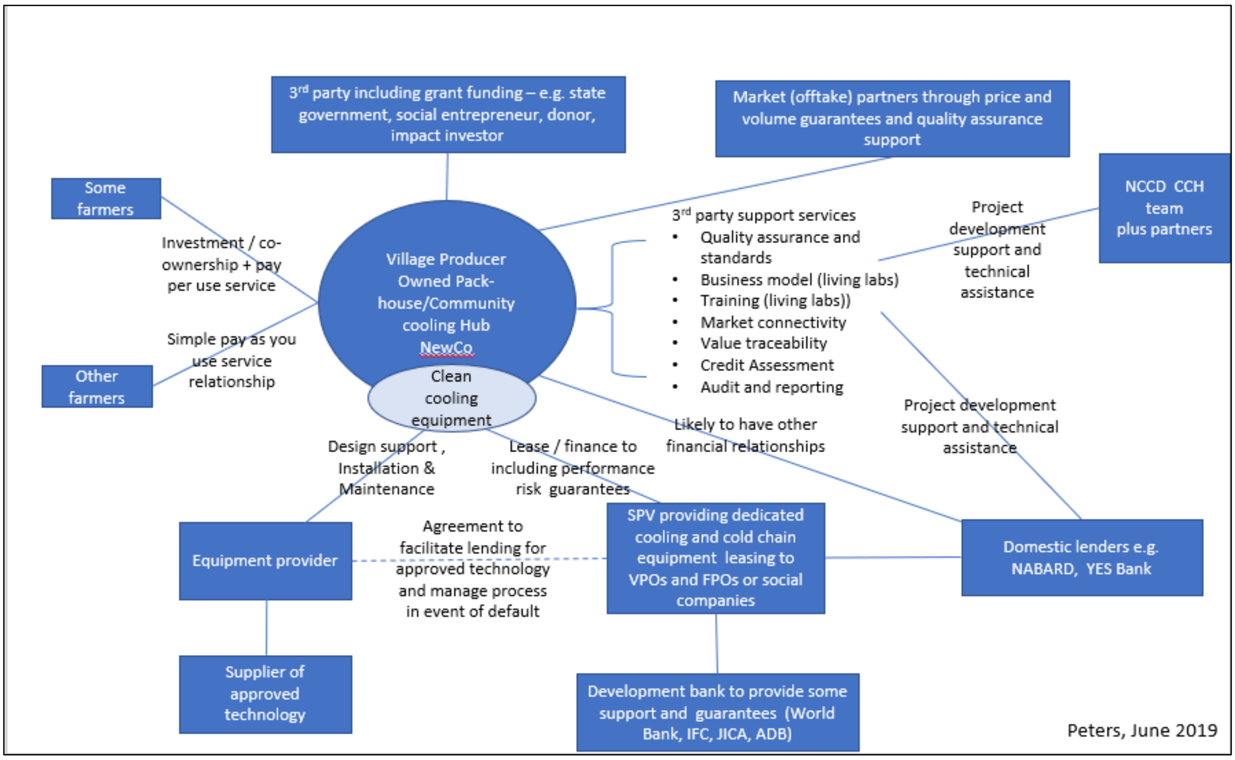

FIGURE 8: COMMUNITY OWNED RURAL COOLING, COLD CHAIN FINANCE AND TRANSACTIONAL STRUCTURE

e) *Governance, Policy and Regulation*

- Focus must be applied to the current governance structures and mechanisms that exist within various levels and in multiple domains across in-country socio-political and commercial landscapes.

- Transitioning governance structures and mechanisms through new multi-dimensional and interdisciplinary approaches will probably include localizing sustainable energy governance and rural economy policy, prioritization of food loss reduction policy over production policy, and creating appropriate enabling regulatory environments to support sustainable cold-chain deployment within the reality of the local in-country socio-political conditions.
- Consideration of effective, equitable north-south and south-south partnerships and the fostering of in-country capacity building will also need to be included, with a specific focus on finance, technology, knowledge, education, training, and skills.

Public-private partnership - Collaboration between private and public sectors has proven to be beneficial for the success of several developmental initiatives. For example, the national centre for cold-chain development (NCCD) in India was established as a public-private *knowledge* partnership, to re-examine strategic assessments and to maintain relevance with future developments. Evolved as a policy think-tank, NCCD was primarily tasked to assist policymakers in rationalizing the government's programs for greater effectiveness and efficiency and keeping up to date with new global advancements within the Indian context. This led to a restructuring of related schemes, including fiscal and financial support for cold chain in India.

- Other governments of developing economies should consider establishing a similar cross-dept public-private partnership with a clear remit of delivering clean sustainable cold-chain infrastructure to support rural economic development in their domains.

Policy Intervention - As is now usual with emerging innovative technology (solar, EVs, etc.), government policy intervention should focus on incentivizing the uptake of sustainable cold-chains *but linked to energy efficiency and decarbonization*.

- Decarbonization could be encouraged through energy excellence using a reward, not regulation, to drive decarbonization. Such an approach can be technology and "stage of cold-chain" agnostic and offer three tiers of intervention – bronze, silver, gold - with more finance incentive linked to deeper decarbonization.
- Cold-chain deployment requires supporting infrastructure to either be in place or developed, including access to clean water, a reliable power source, and adequate

roads and rail systems, and this needs to be an enabling policy priority for developing economy governments.

- ✓ Other areas for policy intervention include R&D investment, where historically cooling has received little attention; food loss reduction; knowledge, education, training, and skills; dumping of used/conventional equipment.

f) *Technology Procurement*

- ✓ A strong relationship with the key in-country and out-of-country suppliers will need to be established to ensure a consistent supply, quality of inputs and effective, equitable north-south and south-south partnerships as well as foster in-country manufacture and capacity building. [76]
- ✓ Bulk-procurement programmes can help the next generation of clean, sustainable technologies penetrate the market by aggregating demand for technology and establishing a demand market for participating manufacturers, thereby leading to a rapid reduction in prices.
- ✓ FPOs and FCOs could minimize their costs through bulk purchase of inputs and equipment or joint hiring of technical experts and clerks to facilitate skills training, equipment implementation and regulatory compliance.
- ✓ Through producer organizations, smallholders can jointly make investments in cold-chain equipment (e.g., cold storage) and maintenance services.
- ✓ Optimizing procurement and implementation of IT tools, such as the geographical information system (GIS), could be used to minimize procurement expenditures. An example of the latter might be the use of GIS and IT tools to assess the perishable food procurement potential of bulk chilling units available in different villages in the locale and help in making business decisions such as the value in engaging with these facilities as potential procurement center partners.

[76] Consolidating the supplier base allows for increased leverage with the suppliers (e.g., giving longer payment terms, lowering the investment in inventory and improving cash cycle) and lessens the administrative burden of managing purchases and payments from and to the suppliers.

g) *Centers of excellence for demonstration*

- ✓ Clean Cold-chain Living Labs and Innovation Centers need to be established to test, validate, and demonstrate innovative and integrated solutions (technology and business model) for sustainable clean cold-chains in the real world based controlled environments.
- ✓ These labs should test and show not only technologies but also the potential for climate change mitigation, funding models, business models and approaches to governance. These labs should be technology agnostic and identify the positive and negative consequences of deploying any new interventions.
- ✓ Clean Cold-chain Living Labs and Innovation Centers will require appropriately skilled and trained staff complements, equipped with essential technologies and testbed facilities (packing, cooling and/or temporary cold storage, leasing reefer vehicles and other equipment and tools for improved post-harvest handling), to also provide training and advisory services through evidenced-based demonstrations. This would also include Business Incubation Hubs delivered through the participation of business schools with expertise in supporting rural enterprises.

h) Training

- ✓ A synergistic collaboration with different sectors, development of appropriate curriculum and training program designs for different food supply chain actors and service providers, and effective implementation of various outreach methods, including “training of trainers” programs and local post-harvest innovation platforms will be essential for successful sustainable cold-chain development.
- ✓ Using the Living Labs described above, training should include Business incubation skills to support FPOs, FCOs, social entrepreneur organizations and businesses to maximize prospective value-chains.
- ✓ For sustainable cold-chain development, training should engineer, repair service workers, storage and transport operators and private sector consultants.

COOLING AND THE COLD CHAIN IN THE ARTISANAL FISHING SECTOR

THE CONTEXT

The global fish production reached 171 million tons in 2016, with aquaculture (farming) accounting for 47% of the world's catch and artisanal fishing accounting for roughly 25%.[77] About 88 % of 2016 fish production (more than 151 million tons) was for direct human consumption. Fish consumption is projected to rise 58 % between 2010 and 2050.[78] However, FAO estimates 35% of all fish caught globally is wasted mostly because of a lack of knowledge or equipment, such as makers. Loss or wastage between landing and consumption accounts for about 27 % of the landed fish. Some estimations indicate up to 50% of the fish caught is lost at the post-harvest level in Africa.[79] Among the four types of fish losses (physical, quality, market and nutritional), the most common is quality loss.[80,81] For small-scale fisheries in lower-income countries, quality losses account for more than 70% of total losses, compared with only 5% physical losses.[82,83]

FIGURE 9: LOCAL COMMUNITIES AND ARTISANAL FISHING

Losses impact those in developing countries significantly since it is a major component in their diet and the industry is responsible for a sizable amount of jobs and earnings generated.[84,85] In the primary sector of capture fisheries and aquaculture, 59.6 million people were engaged (on a full-time, part-time, or occasional basis) in 2016 – 19.3 million in aquaculture and 40.3 million in capture fisheries.[86] About 85 % of the people engaged in the fisheries and aquaculture sectors worldwide are in Asia, followed by 10% in Africa and the remaining 4% in Latin

[77] FAO. 2018. "The State of World Fisheries and Aquaculture 2018"

[78] FAO. 2018. "State of World Fisheries and Aquaculture based on SOFIA" Presentation [Available]: http://www.fao.org/fi/static-media/ADG/KMI_fisheries_outlook_Conferece.pdf

[79] FAO. "Post-harvest losses in artisanal fisheries" News Story [Available]: http://www.fao.org/focus/e/fisheries/proc.htm

[80] World Fish Cneter.2016. "At a loss: the big impact of wasted fish on the poor" ***Blog*** [Available]: http://blog.worldfishcenter.org/2016/09/at-a-loss-the-big-impact-of-wasted-fish-on-the-poor/

[81] When the quality of fish deteriorates, it is not necessarily wasted but sold at significantly cheaper prices.

[82] FAO. 2010."Post-harvest losses in small-scale fisheries" [Available]: http://www.fao.org/3/i1798e/i1798e00.htm

[83] Refer to annex 5 for differences between large scale and small scale fisheries.

[84] World Fish Center. n/d. "Why postharvest fish losses most affect the poor" ***Audio*** [Available]: https://www.worldfishcenter.org/audio/why-postharvest-fish-losses-most-affect-poor

[85] Refer to annex 6 for main causes of PHL and related strategies.

[86] FAO. "The State of World Fisheries and Aquaculture 2018." The State of World Fisheries and Aquaculture, 2018. https://doi.org/10.18356/8d6ea4b6-en.

America and Caribbean countries. Within these countries, artisanal fishing is a widespread practice of fishing.[87] The Ocean Health Index states that 90% of fishing jobs are small-scale and that small-scale fisheries create 90 million related jobs once include the full supply chain.[88]

FISH LOSSES IN AFRICA

The reason for loss of fresh tilapia for traders in several African countries was identified by the FAO as the lack of ice and the non-insulated/ refrigerated transport system. In Ghana, quality loss was caused by fish not being properly preserved on board fishing canoes and being mishandled; quality loss ranged from 42 to 87% depending on the species, condition and size of the fish. The quality loss incurred by fish smokers after purchase and just before smoking using the Chorkor oven in Ghana ranged between 11 and 17% due to long bargaining/auctioning of poorly or non-iced fish.

CASE BOX 4: FISH LOSSES IN AFRICA

Post-harvest losses are due to quality, which mainly is driven from improper cooling, which can account for more than 70% of the total loss in a given fisheries value chain and result in not just loss in value but also loss of high-quality protein, important fatty acids and micronutrients.[89] The current cold chains accessible to artisanal fishers have many weak links and mistakes and poor temperatures are frequent. These results in reduced product quality and shortened shelf life of the fresh products.[90] A study investigating post-harvest losses in Ethiopia finds that 57.8% of the 254 fishers that were interviewed reported fish losses due to shortage of refrigeration at landing sites.[91]Removal of fish from the food chain also results in a physical loss and further contributes to reduced availability.

[87] Meaning low-levels of technology and financial set-up fishing conducted mainly by a small group of individuals

[88] The Fish Tank. 2016. "At a loss: The big impact of wasted fish on the poor" Blog [Available]: http://blog.worldfishcenter.org/2016/09/at-a-loss-the-big-impact-of-wasted-fish-on-the-poor/

[89] FAO. 2014. "The State of World Fisheries and Aquaculture"

[90] Magnussen, O., Haugland, a., Torstveithemmingsen, a., Johansen, S., & Nordtvedt, T. 2008. "Advances in superchilling of food – Process characteristics and product quality"

[91] Agriculture and Food Security. 2017. "Assessment of fish post-harvest losses in Tekeze dam and Lake Hashenge fishery associations: northern Ethiopia" [Available]: https://agricultureandfoodsecurity.biomedcentral.com/track/pdf/10.1186/s40066-016-0081-5

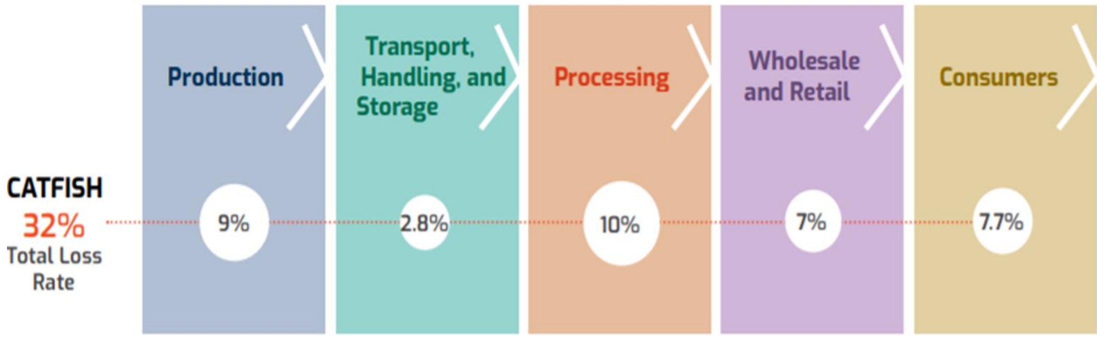

FIGURE 10: CATFISH LOSS AND WASTE HOTSPOTS ALONG THE VALUE CHAIN IN VIETNAM (LOSS PERCENTAGES OCCUR AT EACH STAGE)

Vietnam produces 50% of the world's catfish, with annual production of over 1.25 million tons, However, the total loss rate of catfish is 32%, with the greatest losses occurring at the processing and production stages. In rural areas in Vietnam the supply chain is relatively short but in urban areas the supply chain is longer and less efficient. Cold chains are important for the longer supply chain to ensure that the shelf life and quality of catfish is maintained. Vietnam's expected increase in mean temperature of 1-2˚C and a 180% increase in the number of heatwaves by 2050 will have a substantial impact on the demand for cold chain and cooling peak loads.[92],[93]

CASE BOX 5: CATFISH LOSS AND WASTE IN VIETNAM

While degradation in quality generates a decrease in price to the fishers and nutritional value to the consumer, complete loss of fish is also an issue for the food security and nutrition of millions of people in the developing world since it reduces the offer and drives prices higher for the remaining fish. Several studies find that 65% of fish PHL is due to technical, technological and/or infrastructure deficiencies, coupled with inadequate knowledge and skill in post-harvest handling. The remaining 35% of loss and waste is linked to the social and cultural dimensions of vulnerability, governance, regulations, and their enforcement. [94,95]

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[92] USAID. 2017. "Climate Change Risk Profile: Vietnam" [Available]: https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_Vietnam%20climate%20risk%20profile.pdf

[93] WB FLW Team Country Diagnostic

[94] Diei-Ouadi, Y., Sodoke, B.K., Ouedraogo, Y., Oduro, F.A., Bokobosso, K. & Rosenthal, I. 2015. "Strengthening the performance of post-harvest systems and regional trade in small-scale fisheries – case study of postharvest loss reduction in the Volta basin riparian countries" ***FAO Fisheries and Aquaculture Circular No. 1105. Rome, FAO.***

[95] Wibowo, S., Utomo, B.S.B., Syamdidi, Ward, A.R., Diei-Ouadi, Y., Siar, S. & Suuronen, P. 2017. "Case studies on fish loss assessment of smallscale fisheries in Indonesia", FAO Fisheries and Aquaculture Circular No. 1129. Rome, FAO.

FISH LOSSES IN ASIA

Recent data show fish discarding due to lack of refrigeration contribute to 8.2% of South and South East Asia's seafood waste and loss (i.e., 20% of the total loss). As one example of the impact, Indonesia faces major fish loss problems as the rate is around 40%, which equates to $7.28 billion worth of fish products per year.

FAO's data from six vessels in Indonesia indicated spoilage was largely due to prolonged soaking time, e.g. 12 hours. This combined with prolonged and poor on-board handling and storage with no freezers upon landing, lead to 24.9 tonnes (99 % in weight) in reduced quality, amounting to a 28 % loss in value per trip of the catch. On land, fish sellers have to throw away fish due to lack of proper cooling if the fish is unloaded on jetties with no roofs or soaked in water for too long.

CASE BOX 6: FISH LOSSES IN ASIA

Spoilage in fresh fish cannot be stopped, but it be controlled through executing proper temperature management.[96, 97] Proper cooling is therefore the principal deciding factor of the market value, shelf-life and the quality of fish with the produce remaining as close to 0°C as possible (or is maintained in the frozen state at –18°C or colder). Preservation of fish should begin right after the catch[98] on the vessel and refrigeration is required at each step of fish storage from when it was caught to consumption. [99,100,101,102]

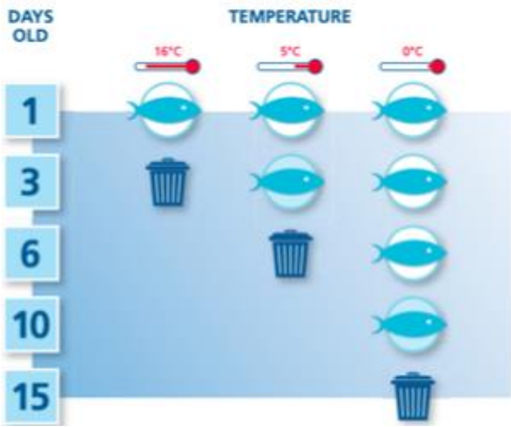

FIGURE 11: THE EFFECT OF CHILLING ON THE SHELF-LIFE OF FISH

[96] Temperature is the single most important factor affecting the rate of fish and shellfish deterioration and multiplication of micro-organisms. Therefore, it is essential that fresh fish, fillets, shellfish and their products that are to be chilled should be held at a temperature as close as possible to 0 °C.

[97] Spoilage begins from the time it is caught due to bacteria, enzymes, oxidation and other various factors.

[98] Fishing practices should also ensure that quality is preserved, by avoiding the dead fish to stay too long in water.

[99] Frederiksen, M. 2002. "Quality chain management in fish processing". Part III – Improving quality within the supply chain. Chap. 15. *In: Bremmer, H.A. (ed.)* Cambridge (England): Woodhead Publishing Limited and CRC Press LLC, 520 p

[100] There can be as many as 12 links of cold chain and more than 20 people will handle the fish through those stages.

[101]https://static1.squarespace.com/static/52a9273ae4b07fa2610392dd/t/5aa9baa90d9297e80c85a233/1521072821711/Cold+chain+in+seafood+industry+v2.doc.pdf

[102] Refer to appendix 3 for list of optimum temperatures and the sort of cold storage required in each step of the fish value chain

THE CHALLENGES AND BARRIERS OF THE FISHERIES COLD CHAIN

(I) TECHNO-ECONOMIC BARRIERS OF ICE

Energy costs [103]

Producing ice under tropical conditions can consume from 55 to 85-kilowatt hour (kWh)/l ton of ice (depending on the type of ice) whereas, in cold and temperate countries from 40 to 60 kWh are required for the same purpose. This may be a large power requirement for many locations in developing countries, particularly in islands and places far from large cities or electricity networks. Ice plants require maintenance and hence trained people and spare parts (in many cases this requires access to hard currency).

Producing and using ice in an economic context

In developed countries ice is cheap and costs only a fraction of the price of fresh fish. In developing countries ice is very often expensive when compared with fresh fish prices. According to the relative cost of ice to fish, ice may or may not be used. For instance, in Accra, Ghana in 1992, it was found that using ice to chill small pelagic (Ghanaian herring) in a proportion of 2-kilogram (kg) ice: 1 kg fish would increase the cost of fish by 32-40%. However, in the case of snapper, for the same ratio of ice to fish the cost increase would be in the range of 4.5-5.7%. The result is that ice chilling of snapper is common in Accra, whereas ice is not utilized to chill small pelagic.

Practical constraints

Introduction of ice into fish handling systems that are not accustomed to using it can create practical problems. For instance, the introduction of ice will increase the volume required for storage and distribution and will reduce the effective fish hold in vessels. The use of ice will also increase the weight to be handled. This will have a few implications such as an increased workload for the fishers, fish processors and fishmongers, and an increase in costs and investment.

The total amount of ice needed per 1 kg of fish, in the complete cycle from the sea to the consumer will be much higher in tropical countries than in cold and temperate regions. As an indication, the average consumption of ice in the Cuban fishery industry was estimated at

[103] Adapted from Huss (1995)

around 5 kg of ice per 1 kg of fish handled (including ice losses), although higher values (up to 8-10 kg of ice per 1 kg of fish) have been recorded in single industries in tropical countries; this necessitates large storage and transport capacities.

Freshwater or seawater utilized for producing ice should comply with standards (microbiological and chemical) for potable water and should be readily available in the volumes required. This is not always possible particularly in countries with energy problems (blackouts) and without (or with erratic) public tap- water distribution. If water must be treated, this implies additional costs and additional equipment to operate and maintain.

Ice is not an additive

When there is a delay in icing, ice is not usually utilized (even if available) because it will not improve fish quality. Consumers could also be intuitively aware of this fact, and they prefer to be presented with the fish as it is (e.g., at the terminal state of its quality) rather than in ice, because in this case ice will increase the price of fish but not enhance its quality. Due to the above and to the problems associated with the transition between artisanal and industrial or semi-industrial fisheries, already discussed, consumers in some countries (e.g., in Saint Lucia and Libya) tend to believe that iced fish is not fresh fish.

Competition for ice

To this end very often fish compete with other sources of demand (soft drinks, beer), even if the ice machine was initially installed to supply ice for chilling fish. This and energy losses at the ice plants contribute to increase the market price of ice.

(II) TRAINING

Trained personnel are required to operate the ice plant and auxiliary equipment efficiently, and to handle ice and fish properly. Although many developing countries have made efforts to train people, in many cases there is a lack of technical personnel ranging from well-trained fish technologists to refrigeration mechanics or electricians, or simply plant foremen. Moreover, in many developing countries it is increasingly difficult to keep technical and professional schools operating in this field, thus jeopardizing the possibility of self-sustained training, and hence fishery industry developments.

(III) BARRIERS TO INTERNATIONAL MARKETS

While artisanal fisheries face several problems due to local and regional problems, they also face some global issues particularly access Barriers to International Markets (Non-Tariff Barrier). [104] This is a particular concern to artisanal fishers and traders as they need to comply with the standards, certifications and eco-labels in the global market.[105] This has been made even more challenging by private standards and certification requirements such as eco-labels which are usually hard to afford by artisanal fisheries. Supermarkets want standardized fish which cannot be supplied by small-scale fishers without a robust cold-chain including monitoring (in addition to capacity to ensure/guarantee a steady supply of fish).[106] Upgrading of landing sites, to facilitate value chain integration through building capacity of small-scale fishers remains a priority need.

INTERVENTIONS FOR IMPACT

(I) EDUCATION

A study in Ethiopia reports that 58% of the 254 fishers that were interviewed reported that they lose fish due to a shortage of refrigeration and transport with cooling equipment. [107] The study however also reports that by simple educational interventions, such as nudging fishers to reduce production when refrigerators were full, or to reach cooling areas immediately and separate spoiled vs. healthy fish resulted in 54% of the

SMARTFISH

SmartFish launched major initiatives to educate fishers in developing countries with supportive and educational videos. SmartFish had been supporting a series of pilot interventions aimed at improving the value chain efficiency of the mud crab industry in Madagascar. The interventions aimed at raising awareness through activities and building on-the-job capacity of mud crab fishers and fishmongers through the promotion of improved yet simple crab storage and transport equipment.

CASE BOX 7: SMARTFISH

[104] UNCTAD. 2017. "Challenges and Opportunities for Small Scale fishers in Fish Trade" ***Presentation*** [Available]: https://unctad.org/meetings/en/Presentation/ditc-ted-28082017-wto2-CUTS-Mukiibi.pdf

[105] Béné, C., Hersoug, B., & Allison, E. H. 201). "Not by rent alone: analysing the pro-poor functions of small-scale fisheries in developing countries"

[106] UNCTAD. 2017. "World Investment Report". [Available]: https://unctad.org/en/pages/PublicationWebflyer.aspx?publicationid=1782

[107] Agriculture and Food Security. 2017. "Assessment of fish post-harvest losses in Tekeze dam and Lake Hashenge fishery associations: northern Ethiopia" [Available]: https://agricultureandfoodsecurity.biomedcentral.com/track/pdf/10.1186/s40066-016-0081-5

fishers following these practices. Therefore, much work from the market side is needed in developing countries. [108].[109]

(II) APPROPRIATE FISH HANDLING TECHNOLOGIES

Cold Boxes

The usage of insulated boxes could be encouraged for better handling of fresh fish on the boats and cold-chain maintenance. Insulated boxes would not only help the fishers to keep their catch to be iced and chilled immediately, hence, extend its shelf life; they would also help protect their catch from physical damage and contamination. However, use of insulated boxes should take place in the frame of good practices in fish handling to be efficient.

Cold stores/cold chain

A cold chain will also require chill rooms (onboard and on land), insulated containers, insulated trucks, and other auxiliary equipment (e.g., water treatment units, electric generators). Besides increasing the cost, all this equipment will increase the technological difficulty associated with the fish cold chain.

(III) JOINED-UP STRATEGIES

Efforts both through the FAO and the Indonesian government have been initiated for developing cold-chain systems, especially for capture fisheries. On-board fish freezing was improved, insulated boxes were installed. Further, cold storages were used in all the fishing posts (around 1,400), ice production facilities were established, fish transportation was strengthened with refrigeration practices and the use of insulated boxes was promoted. The results were positive with improvements in quality and loss reduction.

[108]SmartFish. n/d. “Reducing Post-harvest fish losses for improved Food security” [Avbailable]: http://www.fao.org/3/a-bs226e.pdf

[109]SmartFish. n/d. “Enhancing value-chain performance for mud crab in Madagascar” [Avbailable]: http://www.fao.org/3/a-br806e.pdf

(IV) MACRO-LEVEL INTERVENTIONS AND STRATEGIES

Regarding macro-level interventions and strategies, the FAO's Programme for Integrated Development of Artisanal Fisheries (IDAF) states that a coordinated approach should be built, among others, on four principles[110,111]

1. **Integrated Approach**: Modern technologies and techniques cannot be introduced to manage the catch unless processing capacities are also provided and the full cold-chain, and they are supported by training
2. **Mobilization of Local Development Effort:** Artisanal fishers, and fish folks in general, have the capacity to carry out various activities if supported with incentives and the training. The mobilization of local and national resources, skills, finance, and markets for the development effort, so that outside support remains supplementary or catalytic. Progress that is locally earned will be locally owned, still ready and working after outside experts or facilitators have departed.
3. **Data Collection:** The needs, progresses and the viable solutions of the artisanal fisheries cannot be found with the current inadequacy regarding data availability. Many studies are small scale, focusing on a small segment on fishers. This hinders aggregation purposes which drive global policies, investments and other aid solutions that should be considered for artisanal fish folks. Finally, many studies discussed above focus on improving fishing techniques to combat with physical losses and discard rates. However, these rates are quite low with small-scale fisheries and the urgent problem is the quality loss, which the lack of cold-chain and associated good handling practices are the direct contributors.
4. **Gender and Equity:** Explicit attention to enhancing the economic and social role of women in fish processing and marketing as well as in family maintenance be encouraged through the institution of special programs for women.[112] They make up a considerable portion of the labor market in artisanal fisheries' value chains, as for instance, women account for more 14 % of workers in primary capture fisheries and aquaculture in 2016 and their presence can be particularly high in activities such as gleaning, processing or marketing.[113] If the primary and secondary sectors are

[110] FAO. n/d. "Ten Years of Integrated Development of Artisanal Fisheries in West Africa" [Available]: http://www.fao.org/3/ac885e/AC885E02.pdf

[111] Refer to annex 6 for main causes of PHL in Fisheries and Aquaculture value chains and loss reduction strategies

[112]Mediaprod. 2016. "Voices from Artisanal Fisheries" [Available]: https://www.familyfarmingcampaign.org/archivos/documentos/voices_from_african_artisanal_fisheries.pdf

[113] FAO, 2018. - SOFIA

considered, the workforce would be evenly divided between men and women.[114] Support to enhanced value chain with cold chain could therefore help to fill the gender equity gap[115].

[114] Montfort. 2015. “The role of women in the seafood industry”
[115] Ibid.

IN FOCUS: LESSONS FROM INDIA

ISSUES WITH DEMAND PROJECTIONS

The infrastructure demand projections made in India's NCAP are based on figures that used population growth, urbanization and a 'consumption factor' to determine the volume of refrigeration required across the nation's cold chains. The resulting figures are not based on the quantity of products needed to be stored and moved for the minimum nutritional needs of the population to be met. As a result, the relationship between the development of cold-chains and food insecurity is not explored. Further, it is not evident that the presented estimates of the future cooling demand load for each aspect of cold-chain infrastructure have considered climate change projection scenarios. This could mean that the figures in the NCAP have been significantly underestimated. Despite this, the plan predicts that energy consumption from the nation's cold chains will nearly triple in the next two decades, jumping to 212 TWh from 71 TWh in 2017. This level of increased demand is equivalent to the electricity generated by about 30 full-sized power plants, many of which would likely be powered by high-polluting coal.[116]

Additionally, analysis suggests that in India, average energy expenditure for cold-chain amounts to almost one-third of total operating costs, a share approximately three times above the average levels in developed countries. Although the percentage may differ in other economies, this example from India underlines the fact that energy expenditure currently accounts for a substantial share of a cold-chains' operating costs in developing countries. Reasons for this discrepancy include the geographical dispersion of producers, small landholdings, and a lack of uniformity in cropping, which results in the need to establish multiple, small farm gate collection centers and often low capacity utilization. A lack of two-way cargo movement, especially for refrigerated transport, and the resulting high transportation costs further add to the high overall operating costs within cold chains.

THE FUNDING LANDSCAPE

The GOI and some governments of the individual states of India are, through Prime Minister Modi's Doubling Farmer's Income (DFI) mission and the promotion of agriculture and export,

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[116] Appenzeller, Tim. "Coal Burning, Fossil Fuels, Pollution - National Geographic." Coal Burning, Fossil Fuels, Pollution - National Geographic, June 17, 2019.

providing subsidies, grant-in-aid, and soft loans for supporting farmers, FPOs and private entrepreneurs. [117] In practice some of these incentives have worked better than others but a lot more on-the-ground support needs to be provided to develop the projects themselves, so the government subsidies are directed and used well.[118]

Of note is that the Crop Cluster Development Program (CCDP) instigated by Haryana's Department of Horticulture is one of the most progressive and advanced schemes to-date for promoting clean and efficient cold-chain infrastructure. Working in collaboration with the Small Farmer's Agri-Business Consortium of Haryana (SFACH), the Department has developed crop clusters, assessing the tonnage of production and growth season for different crops and has an overall budget of $73million for providing up to 70% subsidy to co-located FPOs for cold-chain infrastructure development including pack houses, ripening chambers, sorting and grading facilities, cold storage and reefer vehicles. The scheme has received proposals from 47 FPOs and has already shortlisted and issued a Letter of Intent (LOIs) to 21.

However, despite these schemes, investment in cold storage facilities without integrated cold-chain capability continues to be prevalent, as witnessed by a significant increase in such projects in recent years. [119]Data compiled by the Union ministry of food processing showed the government approved 93 cold storage developments worth around Rupees (Rs) 28.3 bn in the calendar year 2017, compared to three such deployments with an investment commitment of nearly Rs 0.6 bn the previous year. In January-February this year (2019), 14 projects worth Rs 3.3 bn have been approved. This recent sharp increase, in the number of projects and investment commitment, indicates investors' growing confidence that the sector will deliver higher returns. Still, even this pace is insufficient to meet the emerging requirement.[120]

CASE STUDIES

A range of case studies is presented below to illustrate how Indian farmers and entrepreneurs are leading the world in the creation of new business and finance models that enable sustainable development based on improving the socio-economic well-being of smallholders.

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[117] A number of these GOI schemes, along with those from the Government of Haryana, are listed in annex 7

[118] Shakti Foundation. "Promoting Clean and Efficient Cold-Chain In India"

[119] Based on interactions on the ground in India with a range of cold-chain users and stakeholders, a SWOT (Strength, Weakness, Opportunity, and Threats) analysis was recently performed and can be found in the appendix 4

[120] Business Standard. 2018. "Cold storages: Nearly 50-fold rise in projects approved by govt incentives" ***News Story*** [Available]: https://www.business-standard.com/article/markets/cold-storages-nearly-50-fold-rise-in-projects-approved-by-govt-incentives-118031300784_1.html

Government Commissioned Packhouses to Support Mandis[121]

Packhouses commissioned during the period 2010-12 by the Haryana state government at *mandis* located in Shahbad, Panchkula and Kurukshetra are available on lease. The *mandi* at Panchkula is equipped with a packhouse of 5 metric ton (MT) capacity, and this is operated by a local FPO that includes more than 300 marginal farmers selling a variety of fruits and vegetables sourced from their fields in the region. Every participating farmer has been given a membership card to occupy and set up a small retail shop in the space provided at the *mandi*. The FPO also manages wholesale trading of other agricultural products. Similarly, individual farmers or groups of farmers and FPOs run *mandis* at Shahbad and Kurukshetra. The packhouse at Shahbad has one pre-cooling unit of 5 MT; storage capacity for more than 100 MT of produce composing 25 MT cold storage units for potato and other vegetables and fruits, and a 20 MT ripening chamber.

Despite the availability of these facilities, the packhouses in Shahbad and Panchkula are reported to be underutilized and the reasons for this situation are:

- A lack of appropriate infrastructure for transporting the produce from the farms to the packhouses.
- Limited financial capacity of marginal and small farmers to store produce which forces them to realize the cash value of their product as soon as possible in distress sales.
- The prohibitive cost of electricity coupled with low operational efficiencies.

Crown Fruits and Vegetables Producer Company Ltd., Kurukshetra, Haryana

A multi-crop FPC, the company's primary produce consists of potatoes, tomatoes, onions, capsicum and cucurbit. Most farmers in the FPC sell their produce at local markets, but through the CCDP scheme the company aims to reach markets in Delhi and Himachal Pradesh and realize higher selling prices while simultaneously reducing the wastage of produce, which is currently estimated at 15-20% of the total. To this end, it is investing in commissioning an integrated packhouse with three lines for sorting, grading, and packaging.

The FPC is planning to transport the products through regular open haulage trucks to Delhi in a single day, and reefer vehicles will be used for transporting the produce to more distant markets in Himachal Pradesh. As an example of the anticipated uplift in income that will result,

[121] MPEnsystems, et al. 2019. "Promoting Clean and Energy Efficient Col-Chain in India"

tomatoes are currently sold locally at an average price of $0.07 per kilo. In the new target markets, the same produce will fetch up to $0.56 per kg. The cost of the additional supply chain components required to reach those markets is expected to be around $0.25 to $0.29 per kg, thereby returning to the farmer at least four times the current sales prices.

Optimal Agro Producer Company Limited, Ambala in Haryana

Optimal Agro Producer is an FPO with 160 farmers and annual aggregate production estimated at 7100 MT, comprising of mainly papaya, marigold, sweet-corn, capsicum, tomatoes, and bananas. It plans to sell the produce at the local Mandis and in the more distant Azadpur Mandi located in Delhi.

Using funding provided by the CCDP, the FPO is investing in commissioning an integrated packhouse with processing lines for grading, sorting, and packaging, as well as seven ripening chambers each of16 to 20 MT capacity, a cold store with a capacity of 20 MT and one pre-cooling chamber capable of handling16 to 20 MT of produce.

The FPO estimates that implementation of a cold chain will provide scope for expanding the markets up to Kolkata, Siliguri, Hyderabad, Kota, and Mumbai, resulting in an increase of 8x in the product sales price and reducing produce losses to 5%. Further, after a few modifications in farming processes, the produce will be compliant for accessing markets in the United Arab Emirates (UAE).

AHA LLB, Himachal Pradesh

A private company run by a progressive farmer and entrepreneur, AHA LLB produces 3500 MT of iceberg lettuce, tomatoes and capsicum through contract framing annually and supplies to Quick Serving Restaurants (QSRs), such as Subway and McDonald's, using reefer vehicles for the transport of produce to Delhi and Mumbai.

Currently, 400 farmers in AHA's portfolio cumulatively own 500 acres of Himachal Pradesh farmland, and the company provides full assistance to them in terms of capital investment for nursery development (such as drip irrigation, power pumps, sprinklers, technical inputs, monitoring and scheduling) as well as a guaranteed 100% buyback that provides protection from the risk of market shocks. The company owns cold storage facilities and maintains integrated end-to-end cold chains through contracting. Having an established business, the company now aspires to expand agricultural activities on in its land in Shahbad and is considering investing in an associated packhouse of 15 MT.

Sahyadri Farmers Producer Co. Limited

Sahyadri was initially founded in 2003 by ten farmers, each with less than one hectare of land, to access export markets for their produce. In 2004 they obtained their first direct order and shipped four containers of fresh grapes to the European market. In 2011 they rebranded as 'Sahyadri Farmers Producer Co. Limited' a 100% farmer-owned, professionally managed, grower-producer company, operationally sound with the best use of technology.

Sahyadri has subsequently grown to become the largest FPC in India, with a membership of 8,000 farmers and a turnover of $45 million. It is the country's largest grape exporting company, and commentators suggest that it will revolutionize the fruits and vegetable business in favor of growers, just as Amul did for milk producers of Gujarat. Beyond fresh perishable produce, Sahyadri has expanded into more sophisticated cold chain enabled markets and are one of India's leading producers, wholesalers and exporters of frozen vegetables and frozen fruit.[122] The Future Group, a leading retailer in the nation's food and fashion sector, has signed a memorandum of understanding (MoU) with Sahyadri Farms for direct sourcing of fruits and vegetables for its supermarket chain 'Big Bazaar'.

An inspirational success story, Sahyadri's business model is based on a parent umbrella FPC structure with a direct membership of farmers, all of whom have voting rights. The company has consistently preferred FPCs as members, each consisting of around 2,000-3,000 single commodity farmers, and provides compelling proof that sustainable socio-economic development based on smallholder farmers is achievable with appropriate business and finance models.

[122] India Times.2018. "How farmer producer company model can transform Indian agriculture" ***News Story*** [Available]: https://economictimes.indiatimes.com/news/economy/agriculture/how-farmer-producer-company-model-can-transform-indian-agriculture/articleshow/66000269.cms?from=mdr

UNINTENDED CONSEQUENCES

The invention and adoption of artificial refrigeration and cold chain have triggered enormous and far-reaching transformations, at scales ranging from our own lives and health to the health of our planet. Even if cold-chain can be provided sustainably to all, it remains capable of remodeling our entire relationship with food – for better in some ways, but also potentially, in others, for worse. Introducing more affordable and readily available means of cooling in the food chain is not just a matter of adding cooling to the status quo; it is launching a major shift to a dynamic socio-technical system. As a result of the dynamics of this integrated system, in response to any intervention, other elements in the system will potentially react, with various degrees of predictability. These dynamics could result in many unintended and adverse effects.

For example, the provision of food supply-chain cooling will, over time, allow some farmers to transition into larger-scale, more diverse businesses. This can reverse or stem urban migration by increasing farmers' incomes. However, ambitions to reach distant, or even international markets, using conventional refrigeration technology could lead to an increase in transport-related emissions, rather than a reduction. Cold-chain deployment could also enable farmers in developing economies to transition from staple to high-value (but temperature-sensitive) horticulture, a positive development; but the latter could have implications for water resources from a move to potentially more water-demanding produce. Likewise, the enabling of more processing at the farm could lead to increased local GHG emissions, environmental pollution and packaging demand – with implications for waste streams and resource use.

The effects on gender equality and gender roles are hard to predict, but technologies tend to become incorporated in existing social systems and hierarchies, although they do sometimes have the potential to disrupt them. In male-dominated societies, without careful planning and some intervention, it is to be anticipated that the benefits of new technologies will flow to men, e.g. men will have more access to them, and women's use will be circumscribed; or the benefits accruing to women (e.g. income) will be claimed by men in the household. Cold chains may, however, give women new opportunities and allow them to start new enterprises such as food processing. How new services and opportunities affect, and are affected by, gender dynamics will vary according to the local context and should not be taken for granted or assumed to be easily predictable. As with gender, new technologies and new opportunities may be kept for the benefit of the more potent in communities, while those at the lower end of hierarchies may struggle to find gains. The ability to invest can also be important in this regard.

Caste can be an issue in terms of who is admitted into groups, which is given information, who is lent money, etc. Other minority groups and disadvantaged groups that need to be considered include scheduled tribes and minority religious communities.

There will always be ‘unknown unknowns’ – but, drawing on a broad and cross-disciplinary analysis of refrigeration’s impact to date, we can at least begin to anticipate many of the possible consequences of the introduction and widespread adoption of cold-chains by developing economies.

RECOMMENDATIONS FOR SUSTAINABLE COLD-CHAIN DEVELOPMENT

- ✓ Help bring the cooling and cold-chain challenge to the forefront of conversations, so can help shape energy and monetary policies in ways that are supportive of future cold-chain needs and thus the needs of the world. Within this, engaging all stakeholders through parallel discussions to define strategies sharing investments and market risks.

- ✓ Work with modelers to quantify the cooling needs in a warming and expanding world and use robust scientific projections to quantify the climate impact of cooling with different energy scenarios, they can make build scientific backing to justify the importance of energy needs and rally international policy more generally to prioritize cooling and cold-chain.

- ✓ Build consensus roadmaps worked on by a comprehensive set of stakeholders to define realistic objectives, interventions and timelines for mapping out, researching and implementing cooling and the supporting frameworks required.

- ✓ Support research and analysis and cascading knowledge, including through Living Labs, so that farmers, producers (especially including mid-sized farmers and Farmer Producer Organisations) and cold-chain operators (mainly including mid-sized farmers and Farmer Producer Organizations) can make informed and rational choices based on robust, comparative performance information and have access to advise and support.

- ✓ Development of a clear roadmap for sustainable refrigeration, not just low GWP refrigerants, to guide long-term strategy. Again, this needs to be about a total system level solution, rather than merely increasing the efficiency of individual pieces of refrigeration equipment, with proper like for like assessments to inform the industry.

- ✓ New Business Models such as 'Cold as a Service'. An 'on-demand' model that focuses on small farmers and those based in the first mile of connectivity that requires cooling access but have limited purchasing capability. CaaS sees end-user customers paying for the cooling on an as-used basis, with a Farmer Producer Cooperative or a third party funding the capital, infrastructure and operational and maintenance costs. The latter recover their costs by usage payments made by the customer. CaaS models can benefit farmers through removing the economic burden of upfront capital investment.

- ✓ Governments need to provide incentives and support for end-users to leapfrog to low-impact, not just natural refrigeration, solutions. This need not necessarily involve subsidies but financing structures which recognize that equipment and measures that may have higher upfront capital costs recouped over life through efficiency gains.

- ✓ Capacity building of technical staff, engineers, and operators to understand and adopt the necessary shift towards natural and green refrigerants including managing and maintaining of energy saving systems.

- ✓ A vital issue already is the lack of qualified engineers. This is already seen as a challenge during the shift to natural refrigerants, but it also has the potential to be a significant limiting factor if we fail to consider long-term maintenance to reduce leaks and maintain energy efficiency when specifying technologies.

- ✓ Protocols. We must stop the developing markets being the dumping ground for low efficiency or end-of-life high polluting equipment, which increases the risk of locking developing countries into unsustainable technology pathways.

- ✓ Public-private knowledge-partnership to drive change. India is the only country to set up a national centre for cold-chain development (NCCD)[123]. Set up as a public-private-knowledge-partnership[124], it has undertaken widespread knowledge dissemination on cold-chain applications, processes, and technologies. NCCD also released the minimum system standards and guidelines[125] for use when creating various infrastructure components. Similar initiatives can be taken by other countries and such centres can function as nodal network for intergovernmental liaison and exchange on global cold-chain initiatives.

- ✓ Such initiatives are also seen on behalf of private industries and agencies, but they all need to be buttressed with strategic government support, with the objective of meeting commitments made on GHG emissions and the SDGs.

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[123] https://nccd.gov.in/

[124] Public-private-knowledge partnership – redefining the cold-chain, Agriculture for Development, No 36. Spring 2019, p 11-15

[125] Guidelines and minimum System Standards for Implementation in Cold-chain, www.nccd.gov.in/PDF/NCCDGuidelines2014-15.pdf

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APPENDICES

1. EQUIPMENT, ENERGY AND CO2E ASSUMPTIONS OF COLD CHAIN

		Business as Usual		Cooling for All	
Stock	**2018**	**2030**	**2050**	**2030**	**2050**
Domestic refrigeration	1,607,816,000	2,557,925,000	3,721,885,200	3,103,795,666	4,336,493,469
Commercial refrigeration	86,071,650	106,580,300	119,886,300	108,898,160	130,123,568
Industrial refrigeration	581,139	642,555	679,677	1,592,498	2,169,830
Transport refrigeration unit	2,727,167	3,236,991	3,428,661	8,618,139	11,675,365
Total	1,697,195,956	2,668,384,846	3,845,879,838	3,222,904,463	4,480,462,232

		Business as Usual		Cooling for All	
Energy (GWh)	**2018**	**2030**	**2050**	**2030**	**2050**
Domestic refrigeration	566,393	720,703	946,715	877,575	1,106,569
Commercial refrigeration	473,435	556,840	594,225	568,395	640,366
Industrial refrigeration	196,837	216,536	226,292	634,668	867,824
Transport refrigeration unit	11,657	13,724	14,810	51,008	71,554
Total	1,248,322	1,507,803	1,782,041	2,131,646	2,686,313

			GCI		**C4A**
CO2 (mTCO2e) #	**2018**	**2030**	**2050**	**2030**	**2050**
Domestic refrigeration	413	536	693	657	796
Commercial refrigeration	485	573	606	593	679
Industrial refrigeration	261	271	261	881	1,134
Transport refrigeration unit	19	21	21	77	109
Total	1,178	1,401	1,581	2,207	2,718

2. SHELF LIFE AND MAINTENANCE OF FRUIT AND VEGETABLES

Product	Ideal Temp °Celsius	Relative Humidity %	Ethylene Production	Ethylene Sensitivity	Approximate Storage Life
Lettuce	0	98-100	VL	H	2-3 weeks
Water Greens	0-1	90-95	VL	M	2-3 weeks
Cassava Leaves	0-2	95-100	VL	M	10-14 days
Avocado (Hass)	3-7	85-90	H	H	2-4 weeks
Cucumber	3-7	85-90	H	H	2-4 weeks
Hot Peppers	5-10	85-95	L	M	2-3 weeks
Okra	7-10	90-95	L	M	7-10 days
Pineapple	7-13	85-90	L	L	2-4 weeks
Tomato, firm ripe	8-10	85-90	H	L	1-3 weeks
Eggplant	10-12	90-95	L	M	1-2 weeks
Banana	10-13	90-95	M	H	1-4 weeks
Plantain	10-13	90-95	L	H	1-5 weeks
Mango	13	85-90	M	M	2-3 weeks
Watermelon	10-15	90	VL	H	2-3 weeks

Key: VL – Very Low; L – Low; M – Medium; H – High

3. SEAFOOD PROCESSING, SPOILAGE AND TEMPERATURE CONTROL

Processes in fresh and frozen seafood value chains[126]

Step	Processes in the chain
Fishing vessels for fresh fish	Catch, gut, bleed, wash, sort in species, size grade, weigh, icepack, store and unload
Fishing vessels for frozen fish	Catch, gut, bleed, wash, sort in species, size grade, weigh, freeze, store and unload
Collectors	Size grade, weigh, icepack, store and bring to auction
Auctions	Store and auction (sell)
Wholesalers/processors	Size grade, process, weigh, icepack, store and sell. There can be one or several steps of wholesalers/processors in a fish supply chain.
Transport companies	Load, store and unload
Retailers/markets	Process, weigh, icepack, store and sell

Maintaining the Cold Chain to Ensure Product Safety and Reduce Spoilage

LOCATION/ PRODUCT	RECOMMENDED PRODUCT TEMPERATURE	ACCEPTABLE TEMPERATURE RANGE
DISPLAY		
Fresh fish display	0°C to 2°C	0°C to 4°C
Chill display cabinets	0°C to 4°C	0°C to 4°C
Display freezers	Less than -18°C	Less than -18°C
Live bivalve molluscs	4°C to 8°C	2°C to 12°C
STORAGE		
Fresh fish	0°C to 2°C	0°C to 2°C
Processed fishery products	0°C to 4°C	0°C to 4°C
Frozen fish	Less than -18°C	Less than -18°C
Live bivalve molluscs	4°C to 8°C	2°C to 12°C
TRANSPORT		
Fresh fish	0°C to 2°C	0°C to 4°C
Processed fishery products	0°C to 4°C	0°C to 4°C
Frozen products	Less than -18°C	-15°C to less than -18°C
Live bivalve molluscs	4°C to 8°C	2°C to 12°C

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4. FREAZING TIMES FOR FISH PRODUCTS [127]

Product	Freezing Method	Product Initial Temperature (^0C)	Operating Temperature (^0C)	Freezing Time
Whole cod block 100 mm thick	Vertical plate	5	-40	3h 20m
Whole round fish 125mm (cod, salmon, frozen singly)	Air blast 5 m/s	5	-35	5h
whole herring block 100 mm thick	Vertical plate	5	-35	3h 20m
whole herring 50 mm thick on a metal tray	Air blast 5 m/s	5	-35	1h 40m
cod fillets laminated block 57 mm thick in a waxed carton	horizontal plate	6	-40	1h 20m
haddock fillets 50 mm thick on a metal tray	air blast 4 m/s	5	-35	2h 05m
haddock fillets laminated block 37 mm thick in a waxed carton	horizontal plate	5	-40	1h 02m
kippers in pairs interleaved pack 57 mm thick in cardboard carton	horizontal plate	5	-40	2h 15m
whole lobster 500 g	horizontal plate	8	-40	3h
whole lobster 500 g	liquid nitrogen spray	8	-80	0h 12m
scampi meats 18 mm thick	air blast 3 m/s	5	-35	0h 26m
shrimp meats	liquid nitrogen spray	6	-80	0h 5m

[127] http://www.fao.org/3/x5936e/x5936e01.htm

Freezing Rates[128,129]

Freezing Rates[130]	Freezing Characteristics
2 mm/h	Slow bulk freezing in a blast room
5 to 30 mm/h	Quick freezing in a tunnel air blast or plate freezer
50 to mm/h	Rapid freezing of small products
100 to 1000 mm/h	Ultra-rapid freezing in liquefied gases such as nitrogen and carbon dioxide

[128] Johnston, W.A.; Nicholson, F.J.; Roger, A.; Stroud, G.D. (1994). Freezing and refrigerated storage in fisheries. FAO: Rome, FAO Fisheries Technical Paper No. 340, 109 p

[129] Fellows, P. (2000). Food Processing Technology - Principles and Practice. Chapter 21 Freezing, Part IV Processing by the removal of heat (p.418-440). Second Edition. Boca Raton, FL (USA): CRC Press LLC, 575 p

[130] Thickness frozen in unit time

5. INDIA SWOT ANALYSIS

	Strengths	Weakness	Opportunities	Threats
Government-owned, available on lease	✓ Readymade infrastructure available (time and resources saved) ✓ No capital investment by users for developing infrastructure ✓ Not affected by market turbulence	✓ End users are not directly engaged – does not cater to the needs of farmers ✓ Lack of manpower, funds, expertise, etc. ✓ Delays in paperwork, daily decision-making processes, etc.	✓ Huge unutilized infrastructure ✓ Easy to provide support through subsidies and schemes ✓ Clean and energy-efficient technologies can be tried and tested ✓ Other formats such as BOT (Build, Operate, Transfer) can be adopted	✓ No economic viability of the facilities ✓ The liability of financial returns is distributed and not guaranteed.
FPO owned	✓ End users are directly engaged ✓ Culture of cooperation promotes the synergy in business processes ✓ Direct share in the monetary benefits of the organization implies efficiency ✓ Improvement of skill sets, knowledge, and awareness on newer practices, procedures, and outputs	✓ The culture of cooperativeness is limited, as groups are solely held together by market principles ✓ Organizational issues - contract designing, distribution of incentives, monitoring of members, landholding patterns, crop selection, collectiveness of resources, etc. ✓ Lack of knowledge of technology and appropriate infrastructure required	✓ Members can provide and exchange resources in the group for the common benefit ✓ Possibility of a streamlined mass production system ✓ Multiplier effect of income generation, employment, and output	✓ Share-holding pattern may create fractions in FPO ✓ Power struggle is an inherent feature. The FPO run facility may be captured by more prominent players, especially who owns the land on which the facility is created

Individual Owned or Private Company	✓ Profits being the core principle leads to better capacity utilization and efficiency ✓ Easy to adopt newer processes and technologies ✓ Easy to develop contracts, for example, contract farming	✓ Attracts large formats ✓ Limited scope for small and marginal farmers ✓ Financial burden is not shared ✓ Capacity to absorb market shocks is minimal	✓ Farm size in Punjab/ Haryana is more extensive than other states; majority farmers have a landholding of more than 1 Acre – Enough to create individual facilities. ✓ Development of entrepreneurship, skills sets	✓ Monetary benefits are concentrated; profits are not shared with farmers ✓ Possibility of over-exploitation of land, water, and other resources, which may pose a threat to food security

ANNEXES

1. COOLING, COLD CHAIN AND THE SDGS

Economic and social development and the environment have to live together; you can no longer have one at the expense of the other. Preferably, our aim has to be a world where everyone can live well and within the sustainable limits of our planet. Rural cooling and in particular cold chain sit at the nexus of this challenge.

		Today		2050	
	SDGs	Cold chains	Space Cooling	Cold Chains	Space Cooling
1	End poverty in all its forms everywhere	✓		✓	
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	✓		✓	
3	Ensure healthy lives and promote well-being for all at all ages	✓	✓	✓	✓
4	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	✓	✓	✓	✓
5	Achieve gender equality and empower all women and girls	✓		✓	
6	Ensure availability and sustainable management of water and sanitation for all	✓		✓	
7	Ensure access to affordable, reliable, sustainable and modern energy for all	✓	✓	✓	✓
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	✓	✓	✓	✓
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	✓	✓	✓	✓
10	Reduce inequality within and among countries	✓	✓	✓	✓
11	Make cities and human settlements inclusive, safe, resilient and sustainable	✓	✓	✓	✓
12	Ensure sustainable consumption and production patterns	✓	✓	✓	✓
13	Take urgent action to combat climate change and its impacts	✓	✓	✓	✓
14	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	✓		✓	
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	✓		✓	
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	✓		✓	✓
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development	✓	✓	✓	✓

2. COLD CHAIN LOGISTICS IN DEVELOPING ECONOMIES

(edited from TAA / GCCA article)

The cold chain, much like the broader food supply chain, is composed of links, each essential to the integrity of produce quality and safety. At its most basic level, these links include post-harvest, transportation, storage and consolidation, and retail.[131] As with any other chain, the cold chain is only as strong as its weakest link. If the cold-chain is interrupted and the controlled temperature-environment compromised or incurs significant delays, or the produce experiences physical damage due to inadequate handling, a cold-chain's beneficial impacts on product shelf life and quality can be jeopardized as a whole.

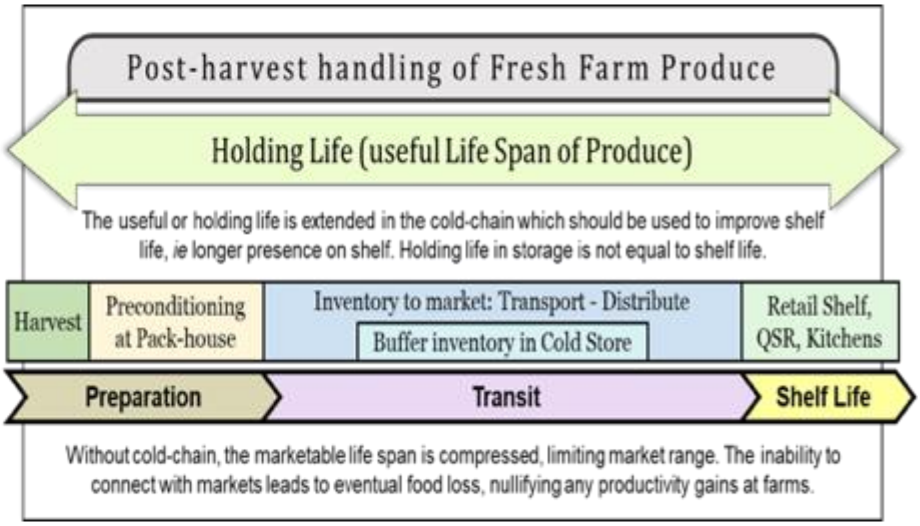

Figure 12: Post-Harvest Handling of Fresh Farm Produce

It should be noted that the cold-chain discussion in this document is exclusively focused on food. However, other products, such as pharmaceuticals and temperature-sensitive medical supplies (blood, plasma and tissues), also require temperature control, and cold-chain for vaccines is a topic of increasing importance as well.

In the development of cold-chains, GCCA has adopted a holistic approach that categorizes each country's cold-chain deployment status into one of four levels; these are illustrated in Table AT1 below.

[131] Processing can also play an integral part of the cold-chain.

Cold-chain Development Level	Description
Start-up or Nascent	General characteristics of a start-up are limited awareness of cold-chain benefits with only a few individuals involved. Erratic use of cold chain primarily for export or for high-end hotels, restaurants and institutions. Cold-chain history is limited and not yet stable.
Developing or Emerging	Characterized by rapid growth, high energy and much activity. Much time is spent developing awareness within functional areas of the business, with limited outreach to other integrated links of the cold chain. Usually initiated on a company-by-company basis, without association or industry oversight. High level of learning necessitated by the rapid growth and limited awareness. Light mechanization is introduced.
Consolidating	Characterized by expanding high-quality service delivery and integrated supply chain management between sectors. Independent companies in each segment of the industry (processing, cold storage, transportation and sales) work together to incorporate cold-chain principles throughout the industry. Most processes rely on mechanization.
Mature or Viable	The integrated cold-chain is fully functional in the competency areas, with businesses reaching upstream and downstream to ensure cold-chain integrity from harvest through consumption for exports and domestic consumption. Being mature across all industry sectors is akin to achieving a level of actual institutional viability. Industry associations provide needed services to ensure sustainability.

Table AT1: Levels of Cold-Chain Development

Although each country's route will differ, understanding the general pathway may help to guide the decisions that are made to support cold-chain growth. Finally, some countries may be considered nascent at one cold-chain link but developing or emerging at another. Categorizing a country should be flexible, not static.

Postharvest

Postharvest handling involves the steps taken to pack and cool fresh food products immediately after harvest or slaughter. There is no substitute for the use of cold temperatures and gentle handling to reduce post-harvest losses, and these handling technologies must be considered pre-requisites to any shelf-life extending technologies. As such, these practices are where cold-chain interventions should begin.

Too often, cold storage is viewed synonymous for the entire cold-chain and considered as the first step in building a sustainable cold-chain. There is no amount of temperature-control that can rescue a product that has already been damaged. Reducing temperature and storing in proper conditions slows down the rate of product deterioration, but if the removal of field heat and steps for temperature control are not taken immediately upon harvest, investment in refrigerated transportation or storage is a disservice. For highly perishable produce, delaying cooling for as little as one hour can reduce shelf life by a full day.

Postharvest practices involve a myriad of techniques that range from no-cost to low-cost to highly advanced and expensive systems for Precooling and cooling. Investments in these systems can build as countries move up cold-chain development levels.

On the farm, it begins with the skills needed to maintain harvested crops at harvest temperature. At a minimum, products are protected from the sun and placed in shade immediately after harvest. Farmers harvest in cool, morning hours. Evaporative cooling, an alternative for countries with low humidity and access to water, may be utilized on-farm. Evaporative forced air cooling can be used to reduce temperatures from ambient temperatures (which can be 30 - 40 ºC) to 12 -15 ºC. Similar to fruits and vegetables, proteins are often sold as fresh products on the day of slaughter and do not see the cold-chain until, at a minimum, a full day's worth of exposure to contaminants and heat. At a minimum, food safety practices such as cleaning with disinfectant as opposed to rinsing areas with water and washing transport packages and vehicles between each use should be common practices. Where feasible, the introduction of cooling can break the chain of hot slaughter to consumption.

Once basic practices are adopted, mechanized pre-coolers may be an option. On-farm locations where precooling is practiced are in clean, covered and well-lit areas. Some producers may begin using Reusable Plastic Crates (RPCs) to store products, as opposed to some traditional methods such as raffia baskets are standard in Nigeria. Some large operations may begin to palletize products.

Once pre-cooling and packaging best practices are followed with some regularity, countries advance to the consolidating stage. Appropriate packaging is in use combined with mechanized cooling and well-palletized products, although the demand for these practices is customarily for the export or high-end markets. Products for domestic consumption do not typically receive the same treatment, at least not consistently.

Cold Storage

Introduction of cold-chain into a developing country too often involves cold storage only, with storage considered as the first step to building a cold-chain. In locations where there may not yet be a business case for investment in a small or large-scale facility, the use of non-mechanized means to maintain temperature is a low-investment introduction. This can involve something as simple as a root cellar. Zero-energy cool chambers (ZECCs) can also be used to store products for short periods in locations with low humidity.

Where the decision is made to invest the capital into building a facility, due diligence should be made to ensure that the cold storage is part of a cohesive chain (with pre-cooling and transport as appropriate). Facility owners should understand the importance of cleanliness and hygiene for food safety and the importance of avoiding temperature fluctuations for food quality. Facility size and design should be based on comprehensive market studies that account for volumes and products. Room for expansion, access to potable water, location for transport options, and access to a power source must all be factored into business decisions.

As facilities develop and grow, they focus on cleanliness and food safety and evolve from cases to palletized storage. Mechanization such as the use of equipment like pallet jacks and forklifts, increases as does investment into equipment like ethylene scrubbers and fans, allowing individuals to meet a greater complexity of cold storage needs.

One trend for cold storage in developing and emerging economies is the use of solar-powered cold storage. Technologically, these work well to maintain temperature on a small scale as most storage units are the size of a refrigerated container or smaller. The difficulty with scalability has been the return on investment for small-scale farmers or small business owners. The price point for importation or installation of one of a solar-powered unit has not yet come down low enough to be accessible on a large-scale.

Generally, initial investments into cold storage are made by high-end retailers or vertically integrated companies who are investing in protecting their brand. The idea of a third-party logistics (3PL) service provider gains strength in consolidating countries who have graduated to the level where temperature control is valuable enough to be paid for as a service, which enables other companies, like retailers, to focus on their core competencies, such as marketing and selling product.

Transport

Transport is traditionally the last and most challenging link in the cold chain to be successfully implemented. Much of this is tied to the lack of road infrastructure, the poor quality of existing roads, inexperienced repair and refrigeration services, and the high cost of diesel fuel. It is also complicated by the need for different types of refrigerated transport, including sea, air, rail and road, but more specifically by the need for refrigerated trucking of various sizes and needs. Certain tractors, trailers, and trucks are designed for bulk, while others are more appropriate for small-scale distribution. Understanding the return on investment for a company's specific business case prior to investing in a refrigerated asset is another common challenge faced when developing the cold chain.

Countries categorized at the nascent level of cold chain can utilize best practices that do not involve investment in an expensive truck. For example, at the most fundamental level, the focus should be on maintaining the cleanliness of truck beds and cleaning cargos between transport. Assuming the trucks are non-refrigerated, the beds should be covered or shaded in a way that allows for proper airflow throughout the shipment. In the case of transporting fruits and vegetables, this may be an open-air truck with slats that allow air to move between the products. Appropriate packaging and packing models to reduce damage inside the truck may be introduced.

As transport develops, and especially as post-harvest handling best practices are instilled, investments might be made either into refrigerated trucking or into technologies that can maintain temperature for short or long-term distribution. Such technologies may include refrigerated trucks, but they could also include coolers, gel packs, or eutectic plates. To facilitate these investments, companies should focus on loading product to minimize damage during transport and scheduling delivery to avoid the hottest part of the day.

At the consolidation level, the utilization of refrigerated transport increases, and to distribute higher quantities of consolidated product, only pre-cooled products are loaded for transport. These companies begin to strive for global food safety standards, with best practices for refrigerated transport and loading, full palletization, and inventory control.

Retail

Often neglected when discussing cold-chain infrastructure, the last link in the chain may be where the most breakdowns occur, especially in countries with large port-based capitals. Product moving into the interior of the country does not often benefit from the cold-chain, and upon arrival, retailers may not understand commodity storage practices for different products.

Most fresh fruit and vegetables in markets are displayed under ambient conditions, which expose them to high temperatures. This causes the softening and shriveling of fruits and vegetables, making the produce unmarketable. When working with retailers on cold-chain practices, especially within-country interiors which may have little or no access to energy and refrigeration, the use of fundamental temperature control practices is still applicable. Examples include shading product, airflows, and food safety practices such as washing hands and crates.

As cold chain grows, the availability of refrigerated display cases may increase among retailers. Initially, these may be used only for drinks, ice cream, and expensive products. On a recent GCCA-organized trip to India, one retailer noted that when they first entered the market, almonds were stored in refrigerated retail display cases while apples were left out in ambient temperatures. The expectation was that because almonds were a more expensive product, they should receive the temperature control. As food safety concerns and consumer demand increases, these cases may be used by other products. Basic operational practices such as cleaning, temperature display monitoring, and closing the doors are essential, especially as these inefficient practices increase costs of refrigeration and cause temperature variations.

Consolidation happens quickly as organized retailers access a larger share of the market and respond to consumer demands. At this stage, retailers may include their cold rooms in addition to the refrigerated displays, with proper inventory management, proper packaging, separation of the product by appropriate temperature zones, and the use of a cold room for an additional product that is not currently on the retail floor. Training of staff on commodity storage and best practices begins to occur as retailers seek to protect their investments

3. TECHNOLOGY AND DEVELOPMENT

Given the many stages of a cold-chain and unique needs at each stage and financial capacity of the farmers, many methods and technologies are used for providing cold chain services in developing markets. These vary from the simple principle of shading to a simple Zero Energy Cooling Chamber (ZECC) working on evaporative cooling principles to technologies which allow Room air-conditioners to be used for cold-stores to sophisticated mechanical refrigeration systems used to maintain cool conditions during post-harvest handling, cold storage and cold transport. The breadth of choice is further expanded by choice or refrigerant including a focus on natural refrigerants – CO2 and Propane – as well as low-GWP refrigerants.

The mechanical refrigeration systems (Vapor Compression) are by far the primary cooling method used and typically utilize electricity for stationary systems and diesel fuels for mobile and off-grid systems. These systems can be costly when used to maintain low temperatures during post-harvest handling and storage, especially in areas where average daily temperatures can reach more than 30°C. Even at this inflated cost, using cold chain technologies can still balance the investment and start yielding profits were combined with market connectivity and business models.

Alternative clean cooling technologies have emerged since the concerns regarding environmental pollution, climate change and the rapid exhaustion of non-renewable resources are on a rise. These include integration of solar photovoltaic (PV) for cold-storage and solar vacuum cooling; waste to cooling sorption cooling; the use of thermal energy storage – ice and PCMs (Phase-change materials) through to radical interventions such as the use of liquid air/nitrogen for zero-emission cooling and power. Further step-change technologies such as solid-state cooling is being researched as well as artificial intelligence (AI) ad system level interventions to increase overall efficiency.

While there have been developments in cold-chain technologies and these will be essential to delivering clean cold-chain going forward, there is a limited understanding of the collective impact that these might have on the delivery of the cold-chain, and its energy and emissions impact. Support to date has been limited to the demonstration of solar cold storage.

Key areas to consider are:

- REDUCE COOLING DEMAND
  - Some common and diverging approaches for reducing demand in the building and mobile sectors include insulation, natural ventilation, shade and reduced solar gain.
  - Shade and reduced solar gain – by protecting a space from direct sunlight, heat absorbed from solar radiation can be reduced, which in turn reduces the need for cooling. This technique is most common in building applications but can also be used in its purest form in the field to protect harvested produce from direct sun.
  - Insulation – which acts as a barrier to reduce heat transfer into a space. It is commonly used in both buildings and refrigerated boxes.
  - Natural Ventilation – most common in buildings, operates by allowing air to flow through a building along carefully designed path.

- COATINGS AND TREATMENTS
  - Innovation in the chemicals industry has produced a range of products that can reduce cooling demand. In the building sector, highly reflective surfaces that minimize solar radiation absorption have been developed, in the food and drug sector, a variety of treatments and coatings have been developed that extend shelf life by trapping moisture, inhibiting oxidation processes or other means.

- COOLING EQUIPMENT, EE AND LOW GHG
    - Transition to low GWP refrigerants
    - Increased efficiency of existing technologies

- FREE COOLING
    - This can range from the harnessing traditional evaporative cooling in more efficient ways to free cooling from water or even the sky (sky-cooling) integrated into the cooling system to reduce mechanical work.

- OFF-GRID PRE-COOLING
    - Removing field heat is a crucial stage in extending shelf-life and quality and should be undertaken before placing produce in a cold store. Pre-cooling the product on entry to the cold chain at optimum temperature relieving duty on the rest of the cold chain. ICL has developed and is demonstrating the world's first off-grid vacuum cooler. Designed in collaboration with The University of Exeter's Renewable Energy Group it delivers blast chilling and vacuum cooling to remove field heat using solar PV technology (8-20 mins per load).

- THERMAL STORAGE
    - Storage is essential both for long-time storage and time-of-use management to address the intermittency of renewables. Alongside electricity, to electricity storage (batteries), a range of useful technologies are available that are effectively storage devices that enable cold to be moved in space or time. They are all "charged" by liquefying or freezing a substance and then absorbing heat (provide cooling) by being melted or evaporated, examples include, ice, cryogenic liquids and other phase change materials. They are often cheaper to buy and operate, can provide more extended off-grid capabilities than batteries as well as not relying on scarce resources.

- ENERGY RESOURCES AND INTEGRATION
    - Waste heat/cold (liquefied natural gas / re-gasification) - recovery and utilization of waste heat or waste cold from parallel processes.
    - Renewables – ensuring cold-chain infrastructure and equipment is integrated with renewable energy networks, both in terms of production and consumption of energy.
    - Use of thermal storage

- MAINTENANCE
    - How well cooling equipment is maintained (e.g. cleanliness, refrigerant charge, how intact the insulation is etc.) can have very substantial impacts on both its effectiveness and its energy consumption. Incorrectly maintained cooling equipment could increase its energy demand by between 10 and 30%.

- SYSTEM INTEGRATION AND OPTIMISATION
    - Given the very different thermal and handling requirements of different products, the matching of technology to product and context is critical, but there also needs to be a broader understanding of how these technologies map together to provide an interconnected cold-chain while minimizing overall carbon emissions, maximizing value creation, and reducing waste. By adopting a whole system

perspective, computer models can be used to evaluate scenarios and strategies that would be hard to capture at scale in the real world. Thinking in this way offers a radical approach to optimization of the local, national and even international food supply chain.

COOLING AT SEA

The length of time a fishing boat can remain at sea depends on the time the fish can be kept so that they are still edible on reaching the consumer. Optimum short-term storage temperature for fish is best kept at 0-2 0C. For a longer-term storage of several months, fish must be kept frozen. The cold chain of fishing will differ slightly depending on the type of vessel and options for cooling at sea is limited particularly in small fishing vessels or boats.

Cooling methods change depending on the type of fish. The size, shape, and the arrangement of the fish impact cooling rates since they may affect packing density, contact areas and the flow of meltwater through the fish layer. Thermal conductivity and different physical properties also influence the time necessary to cool fish, dependent on species and their condition. The influence of all these factors, however, will be small compared to that of the thickness of the fish layer.

REFRIGERANTS ON FISHING VESSELS

New fishing vessels are built to operate with ammonia as a refrigerant; however, an estimate of 70% of the global fishing fleet still used R-22 for all refrigeration applications. An option in new built/refurbished vessels is a cascade system employing CO2 and ammonia. Ice making at sea is demanding due to the lower freezing point of seawater (-9 to -20 degree). Other refrigerant such as R-407A/F, R-507 or R-32 are being used as an alternative to R22 in smaller refrigeration chillers such as Brine or RSW chillers. For larger centralized flooded systems CO2/ammonia cascade system can be used; the safety risk and size of the system is reduced compared with a 100% ammonia system.

The diesel engines of the ship power all cooling activities at sea and this is hugely polluting. The main GHG emissions with wild-capture fisheries are from fossil fuel combustion, which is used for propulsion, organization and recovery of fishing gears, and powering cooling systems. Engines may be oversized to cover all these usages at the same time although not all usages are simultaneous, leaving room for rationalizing and reducing costs.

4. COLD CHAINS AND DEVELOPMENT- DISPATCHES FROM THE SOCIO-ECONOMIC 'COALFACE'

The University of Birmingham's Institute for Global Innovation supported freelance writer Peyton Fleming to explore development progress being made through cold-chain deployments in India, Kenya and Ethiopia. These dispatches, which are presented in the abridged form here, provide insight into the human stories taking place at the socio-economic 'coalface' of rural economic development.

Food refrigeration and cold storage are beginning to take a stronger hold in rural areas of the world that need it most. From India to Africa, new partnerships, solar technologies and government efforts are improving people's lives by keeping fruits and vegetables from rotting and vaccines from going bad through refrigeration. The most significant gains are for small rural farmers who are using cold-chains to grow high-value produce and access lucrative markets, leading to higher incomes, more jobs and other development benefits. Alternatively, this shift is not happening fast enough. While projects are benefitting dozens, thousands, and even tens of thousands of people – it is scant progress against the size of the need. Although notable, it would be useful to learn from these fledgling efforts.

Some of the biggest advances are in India where cold-chain storage access is also a key pillar in Prime Minister Modi's ambitious target to double farmer incomes by 2022. The government is providing subsidies, grants, loans and training to help farmers, Farmer Produce Organizations (FPOs) and private businesses invest in cold-chain logistics, including pack houses, ripening chambers and refrigeration vehicles, known as reefers. Much of the activity is through the National Centre for Cold-Chain Development (NCCD). Last year, the Union Ministry of Food processing reported a 50-fold jump in cold storage projects receiving government support.[132]

Tripled revenue

Seema Gulati and Amit Gupta's Elle Farm in Haryana, India, illustrates the vast upside of providing cold-chain solutions to small rural farmers who grow most of India's food. For years, the couple grew only staples such as potatoes, onions, and carrots, and at harvest time – having no access to refrigeration – they were forced to accept low prices in glutted local markets. Then in 2014, they joined the NCCD, took a cold training course and invested in cold storage by selling land and taking out a bank loan. Now, with a 30-ton cold storage unit, a 60-KW solar system and three refrigerated vehicles, they are growing high-value mushrooms and fresh salad, vegetable, and flower which they are selling in supermarkets in Delhi and Gurugram 250 kilometers away. The farm's revenue has tripled, and its net income has doubled. They are now looking to expand to markets in Mumbai and Bangalore, which could increase their revenues again.

The World's Banana Giant Awakens

Global cooling companies are also stepping up their efforts in India – among those, Danfoss, which is working with the Confederation of Indian Industry to transform the country's massive banana sector. [133] India grows one of every three bananas in the world, yet a third are lost due to poor handling practices, no refrigeration and poor market access.

But that is changing. Danfoss is helping hundreds of banana growers in Tamil Nadu on two fronts: first, by pre-cooling newly harvested bananas to extend their shelf life; and second, with tightly controlled ripening chambers that ensure a reliable product for commercial markets. The results have been impressive. "The two interventions have resulted in three times higher value for the farmers and a

[132] https://www.business-standard.com/article/markets/cold-storages-nearly-50-fold-rise-in-projects-approved-by-govt-incentives-118031300784_1.html

[133] http://files.danfoss.com/technicalinfo/dila/01/Banana%20Ripening_Catalogue.pdf

wastage reduction of nearly 20%," said Ravi Purushothaman, president of Danfoss India, in a recent blog.

For the first time, India's bananas are now being exported to Europe. "Ten years ago, we had 10 employees. Today, 200 families are dependent on this farm," said a banana farmer, Mr. Sivamani, who is part of the Danfoss effort. "New technologies like cold-chains and reefer containers have made it possible."

Cold into Cash: Using cooling to reinvent Kenya's rural food systems

Cicily Wanjira has a big smile when she shows off the plump mangoes dangling from 600 trees on her small rural farm 175 kilometers (109 miles) north of Kenya's capital Nairobi. But the smile quickly turns to a scowl when the topic turns to sell her fruit.

Like most farmers in this lush-green agricultural region, Wanjira sells her crops through local brokers, who buy directly from farmers and then transport the goods to major markets in Nairobi and outside the country. Growers widely dislike brokers, farmers say, because they are unreliable and pay a pittance for their crops. However, farmers have little choice but to sell to them: Lacking refrigeration to keep their perishable crops fresh, they sell to brokers or don't sell at all.

"The brokers are not good," Wanjira says, recalling how they rarely showed up last season when her mangoes were ripe. And when they did arrive, they paid only 5 to 6 Kenyan shillings per kilo, a far cry from the 60 shillings mangoes were fetching at Nairobi retail markets.[134] Her year-end seasonal sales were disastrous: She only sold one-quarter of the mangoes she grew, the rest were left rotting behind her house. "I dug a hole and buried them," she says. Wanjira's experience is too often the norm for millions of small rural farmers across Kenya and the rest of Africa. Nearly a third of the food farmers grow in sub-Saharan Africa is lost due to lack of refrigeration, poor market access and other related factors.[135] Annual food losses for fruits and vegetables are an estimated 40 to 50. But slowly, momentum is shifting. Advances in affordable off-grid cold storage technologies, combined with new initiatives to help rural farmers pool their resources, are creating ripe opportunities to reshape Africa's rustic food systems and cut food losses.

Cicily Wanjira, who buried most of her mangoes last season in Embu County, now has a reliable buyer willing to pay twice as much for her mangoes. "Eight to 15 shillings per kilo, that's good money," she says smiling.

Two-Step Effort

It is a two-step effort. The first step is helping rural farmers gain access to cooling technologies — many running on solar power. The second is assisting farmers in using a scale — by pooling and cooling their crops — to gain critical leverage in deciding when and to whom they sell their goods.

"By bringing smallholder farmers together with cold storage, they can bring their goods together and then negotiate with the buyer," says Dr Jane Ambuko, a senior lecturer at the University of Nairobi, who is spearheading several post-harvest food projects in East Africa. Having shared cooling also enables better processing practices, she says. "With a cold room, you can have 10 tons of product nicely graded, sorted, packaged and ready to be collected [for buyers]."

One of Ambuko's projects is the Karurumo Horticultural Self-Help Group in Embu County, a consortium of three-dozen local farmers, including Cicily Wanjira. With $300,000 from the Rockefeller Foundation, the farmers have built a cluster of cold storage buildings that allow mangoes, bananas, tomatoes and other local crops to stay fresh. Two of the units, a brick-and-sand cooler and a charcoal cooler, are decidedly low tech and rely on evaporative cooling. When water evaporates from the wet charcoal and

[134] https://www.nation.co.ke/business/seedsofgold/Easy-way-to-put-money-in-mango-farmers-pockets/2301238-4354534-vbjx4wz/index.html

[135] https://www.sharedvalue.org/sites/default/files/resource-files/YieldWise%20Case_Final.pdf

sand, it removes the heat from the stored produce. The units are attractive because they are low cost, use no energy and can be built with local materials.

The farmers are also using a third outdoor fruit drying unit, powered by a solar panel, that is making dried mangoes, tomatoes and banana chips that can be sold at better prices. The pilot project in Karurumo that launched in 2018 is all about increasing the value of the farmer's crops and getting higher prices when they're sold to buyers. Already, Ambuko says, a company has expressed interest in exporting the dried fruit products to the Middle East and Europe.

"Once we have the quality products, the prices [we get] will go up," says Aloys Mbogo, a retired farmer who is the chairperson of the Karurumo Self-Help Group.

Supply Chain Fixes

Since 2014, Twiga Foods has built an extensive supply chain enabling 10,000 rural farmers in Kenya to sell their crops directly to retail outlets, kiosks and market stalls across Nairobi. More than 100 tons (91 MT) of fresh fruits and vegetables are being trucked from rural farms into Nairobi every day. The produce is then processed and packaged at a substantial warehouse in Nairobi before being distributed to 5,000 street vendors around the city. Because the crops are collected and moved to Nairobi in less than 10 hours, no cooling is needed in this part of the supply chain.

Twiga is also helping farmers with its extensive cold storage capabilities in Nairobi — much of it being provided by InspiraFarms.

InspiraFarms' 20 cold storage units at the Twiga facility have multiple benefits. They use 70% less energy than traditional refrigeration systems and have up to two days of thermal backup capacity if the electricity goes down, which happens almost every weekend in Nairobi.[136] The units are also equipped with equipment to control the ripening process for all fruits and vegetables. Bananas, Twiga's most significant product, are typically ripened for six days before being distributed to city vendors. Only one % of the bananas are lost.[137]

The overall result is a win-win for rural farmers and urban vendors alike. By cutting out the brokers and other intermediaries, farmers get a higher premium by selling directly and regularly to Twiga, while the vendors pay less than they would if working through a broker.

Among the farmers benefitting is Alvan Muriithi, an Embu County grower who leases 3.5 acres (1.4 hectares) to grow papaws, bananas, tomatoes and maize. Since switching to Twiga just a few months ago, his profits have gone up. He recently sold 125 kilos (276 pounds) of pawpaws at 30 shillings per kilo, nearly double what he was getting from local brokers."They pay well, I'm assured of my payment and they don't have so many conditions," says Muriithi, who is now making enough money to send his two children to private school.With tens of millions of smallholder farmers in sub-Saharan Africa alone, Twiga's and Inspira's efforts are still in the early stages — and financing for large-scale global expansion is a crucial challenge.

But both businesses are growing. Twiga is looking to expand to other major cities in Kenya and Tanzania. InspiraFarms recently delivered ten solar-powered cold storage units to Rwanda that will benefit as many as 100,000 smallholder farmers. The project is backed by the Rwandan government and the World Bank.

The cold truth about Ethiopia's nutrition gap

Most of Ethiopia's refrigeration capacity is aimed at large commercial agriculture ventures, principally for export products such as flowers, exotic fruits and meats. This becomes very clear soon after leaving

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[136] https://www.greenbiz.com/article/how-food-cold-chains-are-improving-lives-and-livelihoods-asia-and-africa

[137] https://www.inspirafarms.com/reshaping-rural-food-systems/

the mayhem of the Altkit Terra Fruit and Vegetable Market in downtown Addis Ababa and driving south towards the city of Hawassa.

Luna Export Meats exports locally sourced sheep, lamb and other meats to the Middle East. It is one of a half-dozen slaughterhouses in this region that have extensive cold room facilities powered by the local electric grid. "They're all commercial and they're all exporters," said Dr Yetenayet. Further south in the Rift Valley, there are sprawling strawberry farms and dozens of greenhouses that are growing cut flowers that will eventually be sold in Holland and other parts of Europe. Again, they all have cold storage.

However, some area farmers now realize the benefits of cold storage by working cooperatively. At the Meki Batu Fruit and Vegetable Grower's Cooperative Union in the Rift Valley, 152 growers banded together in 2012 to secure a loan to build a food aggregation centre that includes a 10-ton cold storage unit. Their fresh produce is now being delivered three days a week in refrigerated trucks to Ethiopian Airlines which uses it for meals. The grower's union offers a vital lesson: Access to cold storage is nearly impossible if you're a small individual farmer; It's simply too expensive. Groups of farmers that can be organized around a viable business venture have a far better chance of financing and building cold storage capacity that will enable them to boost their incomes – while also improving local diets and nutritional prospects.

"Without the cold room, the grower's union would never have been established," said Melesse Abule, a field technician with the farmer's union. "The airline wouldn't buy from us."

Fits and Starts

Progress is not always consistent.

APM Terminals, an international logistics company in Nigeria, learned this lesson just over a year ago. In December 2017, it organized a trial shipment of 18 tons of fresh tomatoes, loaded in crates on a refrigerated truck, for a 1,000-kilometer delivery from tomato-rich Kaduna to the economic hub Lagos. While the tomatoes were delivered, no more shipments have been made due to poorly established retail connections, lack of market demand and road congestion according to Augustine Fisher, African communications manager for the company.

In other instances, solar refrigeration was too costly for rural farmers with limited means and market access. The non-profit group, TechnoServe, learned this lesson working with thousands of Kenyan mango growers to improve their production and post-harvest practices. Farmers experimented with numerous technologies, including small solar cooling units. In the end, fly traps, and better packaging proved to be the best bet.

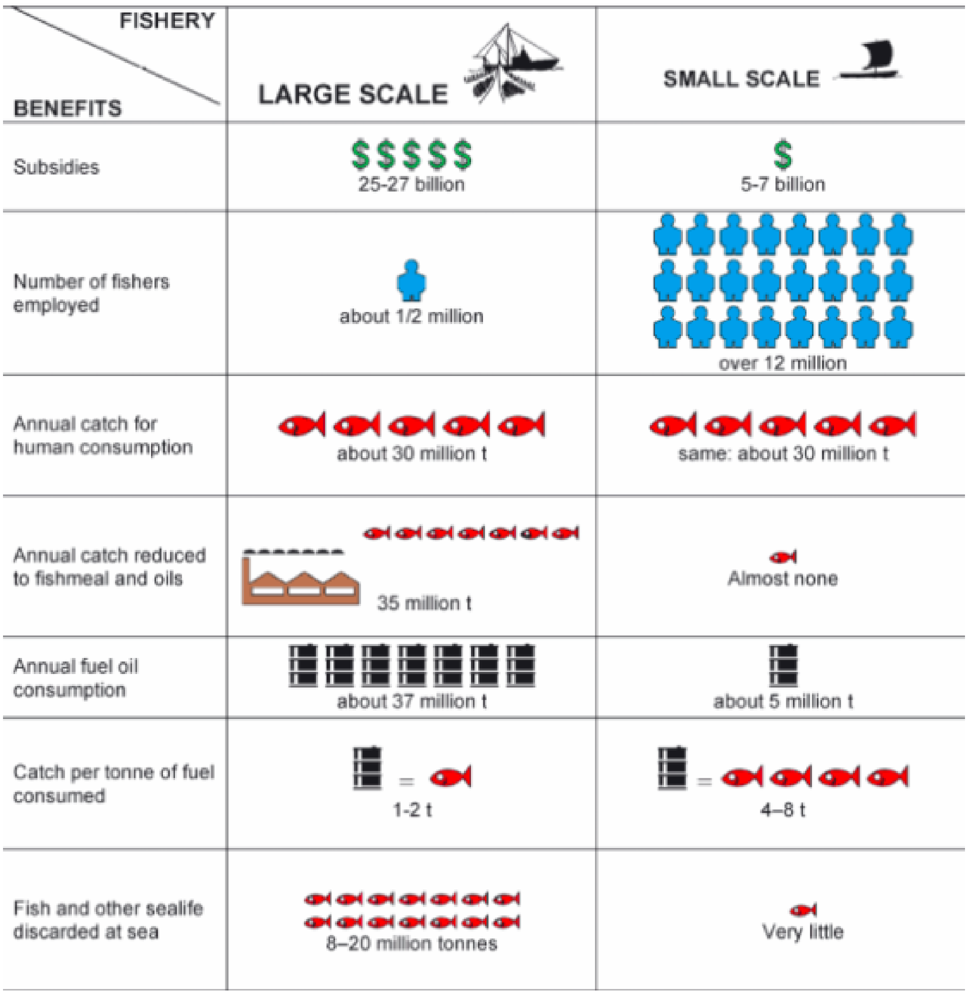
"Unless farmers are fully utilizing the cold storage units for multiple crops, the paybacks are too long," said Isaiah Kirema, program manager for TechnoServe's YieldWise program, a collaboration with the Rockefeller Foundation aimed at reducing food losses in Africa.

Still, TechnoServe's engagement and training for 20,000 growers is yielding results: 82% of the farmers have adopted at least one post-harvest management technology and losses have been reduced by 30%.

5. FISHERS: LARGE SCALE VS. SMALL SCALE

Category	Definitional Elements	Typical Examples
Physical Attributes	Vessel type	Canoe, dory
	Vessel size	Short (e.g., < 10m); light
	Vessel motor	Unmotorized or small engine
Pattern of fishing	Fishing gear/technique	Manual or small nets; passive; low tech
	Location of land base	Rural
	Location of fishery	In-shore
	Target type	Multi-species
Social Structure	Of fishery	Traditional (clan or community)
	Of fishing enterprise	Family crew, owner on board
Economic Condition	Market orientation	Direct consumption or local market
	Income level	Subsistence or very poor

Comparisons between large scale and small-scale fisheries



COOLING BY FISHING VESSEL

- **Small fishing vessel:** Are not generally installed with refrigeration capabilities onboard. For artisan fishers, managing temperature and the use of ice are effective ways to combat with spoilage while maintaining the quality of fish. Depending on the geographical location and availability, these vessels load up ice at the harbor each morning, and the duration of fishing is generally a few hours. The ice-making machine on-land uses R-22 or Ammonia as the refrigerant, and dependent on the location, a diesel engine might be used as the electrical source.

  For a small fishing vessel in developing worlds, their catch usually is sold directly to the consumer or retailer. It does not go through the process of processing or cold storage. Typically, ice is reapplied to the products once on land to keep the cold chain going. However, this situation has evolved in many places, as urbanization, access to market including export and competition with the industrial sector increase. As demand for fish and quality grows, value chains expanded geographically and in length, with more actors and processes, meanwhile fishing lasted longer in search for more fish. The new conditions add time between catch and consumption and changed the conditions regarding seafood preservation, creating more interest in cooling.

- **Medium fishing vessel:** These generally have a fishing duration of a few days up to two weeks and are typically installed with insulated fish-hold, refrigerated ones, possibly refrigerated sea water (RSW) tanks and ice-making machines.

- **Large fishing vessel:** These vessels include a range of refrigeration methods dependent on the seafood value chains they operate in, typically they have blast-freezers, Eutectic plates, RSW tanks and ice machines.

6. MAIN CAUSES AND REDUCTION STRATEGIES OF PHL IN FISHERIES AND AQUACULTURE VALUE CHAINS

Table edited for relevance to cooling[138]

Fish Chain Stage	**Causes of Losses**	**Main type of losses**	**Losses reduction strategy**
Fishing	Discards of fish Too much catch compared to market absorption capacity Improper handling causing bruising Absence of chilling on board Scarce law enforcement and governance e.g. over fishing; improper in vessel storage of fish; fishing in forbidden zones (to preserve marine life), etc.	Physical & Quality	Adjust time of gear time in water; keep fish alive as long as possible Protection of working area against sun Clean / gut fish as soon as possible Use of ice /chilled or refrigerated seawater/brine Freezing at sea Use of fish boxes on-board Landing fish as fast as possible Covering fish with sacking or clothes to avoid direct sun heating/pouring water on it (evaporative cooling) Law enforcement Promotion of consumption towards less valued fish species (utilization of discards/bycatch) Adjustment of catches and landings
Landing	Lack of infrastructure and services conducive to good handling and storage Lack of ice/chilling; Delays in selling/price negotiation Market saturation Fish thrown or drops from containers during unloading and transport Fish on ground exposed to dirt and high ambient temperatures	Physical & Quality/ Economic	Proper landing site, facilities and management of the same; proper planning of product flow and logistics Use of ice on shore Insulated boxes/cold room Implementation of food safety legislation Market and prices information

[138] http://www.sbb.gov.tr/wp-content/uploads/2018/11/Reducing_Postharvest_Losses_in_the_OIC_Member_Countries.pdf

Processing	Low processing capacity to absorb fish landed Traditional processing techniques (i.e. open air and sun drying) Adverse weather conditions (rainy/ cloudy season, as well as climate variations) making drying difficult Poor water quality for washing fish Unskilled workforce Scarce or absent packing system Poor quality raw material for processing	Physical, Quality, Nutritional	Drying on raised racks, mats or concrete surface Using more modern drying techniques Screens to prevent insect infestation (especially blowflies) Good hygienic conditions Use of clean water Use of good quality raw material (fresh fish)
Transport and distribution	Delays in packing, loading, transport causing spoilage Careless handling resulting in physical damage Poor road and transport logistics Inappropriate vehicles Remoteness of fishing villages	Physical, Quality	Use of ice/insulated boxed for fresh fish; Appropriate packaging such as rigid containers Proper packing before transport
Storage	Absence of or poor storage facilities/cold rooms leading to spoilage	Physical, Quality, Nutritional	Properly designed stores to include Good hygienic practice Pest prevention Store management and product rotation (first in first out)
Marketing	Oversupply of fish Lack of buyers Under-utilization of some species for fish meal Mismanagement of fish products imports.	Quality, Economic	Proper market infrastructure and management Implementation of food safety legislation Use of ice/insulated boxes or other preservation techniques Exploiting the economic potential of sustainable by-catch Promotion of value-added products from low value fish species

			Raising public awareness on fish quality and food waste Access to market information Access to more rewarding markets Local and better data collection for just-in-time production and marketing.

7. COLD-CHAIN INFRASTRUCTURE INCENTIVISATION SCHEMES AVAILABLE FROM THE GOI AND THE GOVERNMENT OF HARYANA

GOI SCHEMES			
S.No.	**Scheme**	**Funding for**	**Extent of Funding**
1.	Mission for Integrated Development of Horticulture (MIDH)	Energy Efficient Cold Storage Infrastructure up to 10,000 MT	None available
2.	Scheme for Integrated Cold-chain and Value Addition Infrastructure under PRADHAN MANTRI KISAN SAMPADA YOJANA	Integrated Pack House, Ripening Chamber, Cold Storage Units, CA units, Reefer vehicles and similar infrastructure	Grant-in-aid of up to 50% of the cost for all states and 75% of the cost for the N-E States
3.	SFAC Venture Capital Assistance Scheme	Agriculture and allied sectors	Interest-free venture capital to agribusiness projects by way of soft loans to the extent of 26% of promoter's equity or 50 lakhs ($71,500) whichever is lower.
4.	Central Sector Integrated Scheme on Agricultural Cooperation (CSISAC)	Marketing, Processing and Storage	Grant-in-aid/ subsidy of up to 25% of project cost capped at `5 crores (cr) ($7.1 million) per project per proposal
5.	Financial Assistance under Agriculture and Processed Foods Export Promotion Scheme of APEDA	Agri-Exporters for packhouse, precooling units, cold storage and refrigerated transportation etc., cable system for handling of crops like banana, pre-shipment treatment facilities such as irradiation, Vapour Heat Treatment (VHT), Hot Water Dip Treatment (HWDT), etc.	Up to 40% of the total cost subject to a ceiling of `100 lakhs ($1.4 million) for each of the activities
HARYANA STATE GOVT. SCHEMES			
S.No.	**Scheme**	**Funding for**	**Extent of Funding**
6.	Assistance to set-up Food Parks in 'C' and 'D' category (categories defined as per the location)	Individual units as part of Food Parks	25% Capital Investment Subsidy on FCI (fixed capital investment) limited to `1 cr ($ 1.4 million); 100% SGST reimbursement for 10 years

7.	Assistance to set-up Food Parks in ‘C’ and ‘D’ category	Individual units as part of Food Parks	25% Capital Investment Subsidy on FCI (fixed capital investment) limited to `50 lakhs ($71,000); 100% SGST reimbursement for 10 years
8.	Support for Integrated Cold-chain and Value Addition Infrastructure	Storage infrastructure, packhouses, transportation infrastructure, value addition and processing infrastructure and irradiation facilities.	35% Capital Investment Subsidy on project cost limited to `5 cr ($7.1 million)
9.	Support for establishing backwards and forward linkages in rural areas	For creating effective backward & forward linkages for perishable Agri-Horti produce through setting up of minimum processing facilities such as primary processing centres/collection centres at farm gate, distribution hub and retail outlets at the front end	50% Capital Investment subsidy on project cost limited to `2.5 cr ($3.6 million) for rural areas across state and 50% Capital Investment subsidy on project cost limited to `3.5 cr ($5 million) in rural areas in “C” and “D” category blocks.
10.	Special support to promote integrated packaging of horticulture produce, i.e. Fresh Fruits and Vegetables that are grown in the state	Integrated packhouse (s) for horticulture produce, i.e. fresh fruits and vegetables.	Upper limit of capital investment subsidy to the tune of up to `3.5 cr ($5 million) (50% capital investment up to the limit of `3.5 cr.)
11.	Crop Cluster Development Programme (CCDP) in “Baagwani Villages” under Plan scheme on “On-farm and Marketing Support to Horticulture Farmers”	Setting up the cold-chain related infrastructure	70-90% on the component of eligible project cost up to `6 cr ($8.6 million) per integrated project including plant and machinery

8. KEY RESEARCH AREAS

Technologies – optimization and cost-down in-country delivery	Aggregation	Services
• **Off-grid mobile pre-cooling** • **Ice-production for off-grid fishing communities and others** • **Waste heat to cold (sorption cooling)** • **Harnessing waste cold** • **Thermal energy vectors** • **Zero-emission transport refrigeration** • **PCMs and vending small-scale rechargeable cooling boxes** • **Small-scale refrigerated transport**	• Packhouse as a system *(see overleaf)* • Near-farm mobile pre-cooling and packhouses • Energy- efficient and climate-friendly cold room for the fisheries industry • Agent-based Models for system optimisation (CfSRF*)* • E-logistics and modal shifts[139] • Community Cooling Hubs	• Micro fulfilment • On-demand 3rd Party • Logistics • Information connectivity • Market trading and brokerage via mobile devices • Value-added traceability
and technically trained capacity to deliver and maintain		

[139] As an example of modal shift, due to improving technologies in cold transportation, flowers are increasingly being transported to the U.S. via ocean-going vessels, rather than the traditional, more expensive air transportation option. The United States imports more than 5 billion fresh cut flowers each year. Global shipments of all perishable products by ocean carriers have increased rapidly over the last 35 years. Reasons for the shift include greater availability of refrigerated containers, improved facilities at ports, and better technology options for monitoring shipments in route.