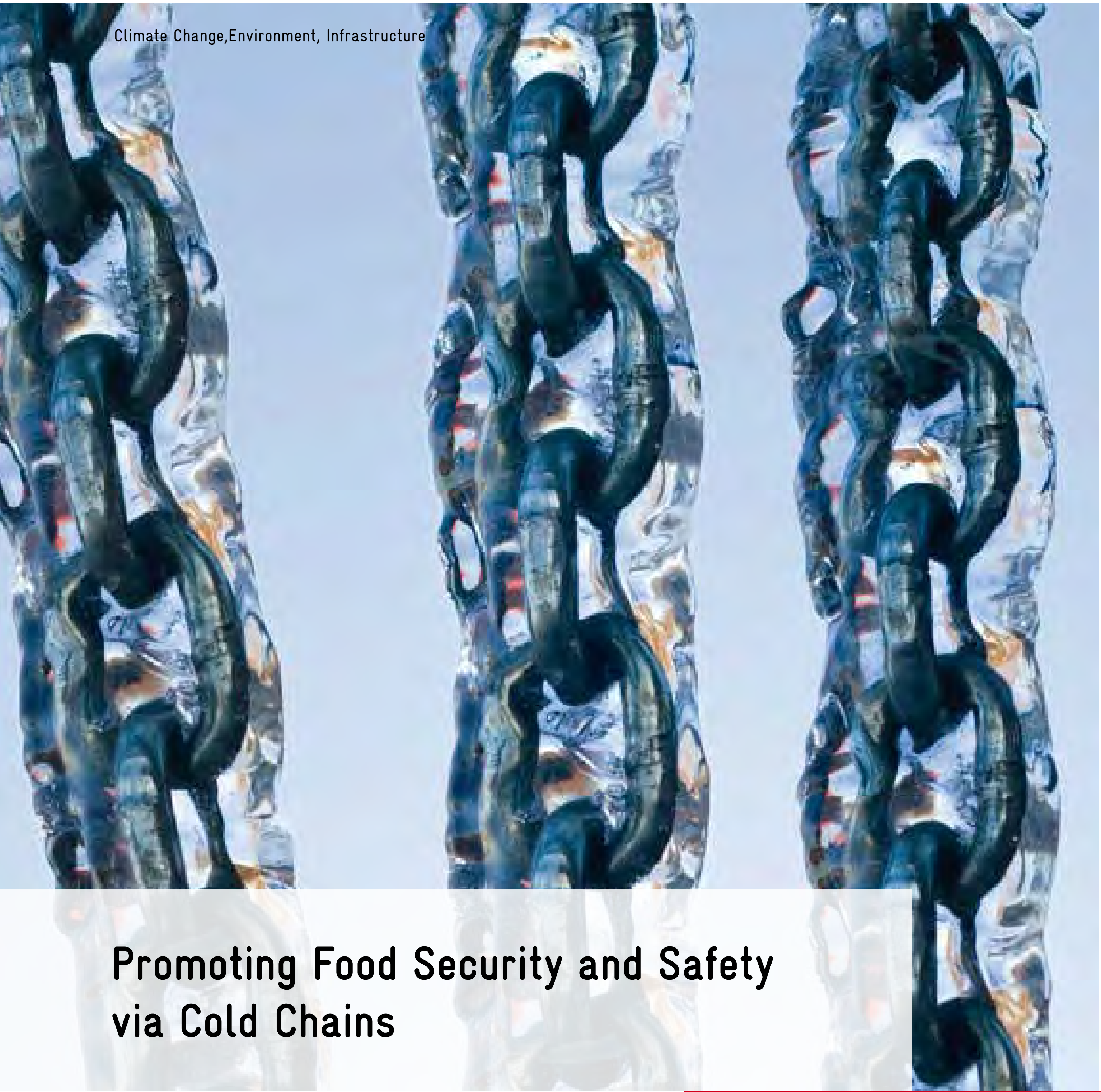
Climate Change,Environment, Infrastructure



Promoting Food Security and Safety via Cold Chains

Technology options, cooling needs and energy requirements

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About this concept paper

The purpose of this concept paper is to present different existing and potential cold chains for food products and to give an overview of existing challenges and possible solutions towards better cold chain coverage, improved cold chain management and reduced food losses in developing countries. The paper aims to serve as a basis for thematic discussion on one field of action to improve food security using climate friendly technologies. Lessons learnt can provide an input for ongoing projects and the development of new projects in the field.

As food cold chains are not at all or not fully developed in many countries, the primary objective of this paper is to gain an increased understanding of well-functioning cold chains, drivers that have helped the development of functioning cold chains as well as barriers that need to be addressed. Energy supply, which is not currently available at a sufficiently high and consistent quality, poses a barrier in rural areas where cold chain elements are lacking. Consequently, the paper takes a look into ways of supplying the energy required for cooling in a climate-friendly manner.

The focus was placed on perishable foodstuffs, more specifically vegetables and fruits, dairy, as well as meat and fish.

Contents

Glossary

Coefficient of Performance (COP) A measure of the energy efficiency of a refrigerating system, which is defined as the ratio between the refrigerating capacity and the power consumed by the system and primarily dependant on the working cycle and the temperature levels (evaporating/condensing temperature) as well as on the properties of the refrigerant, system design and size. The comparable term “EER” or “energy efficiency ratio” is also used.

Depth of Discharge (DoD) A measure used to describe the degree to which a battery is discharged. DoD is defined as the percentage of battery capacity discharged expressed as a percentage of a battery’s maximum capacity. DoD therefore provides a complementary measure to the so called state of charge (SOC).

Global Warming Potential (GWP) An index comparing the climate impact of a greenhouse gas relative to emitting the same amount of carbon dioxide. The GWP of carbon dioxide is standardised to 1. GWP includes the radiative efficiency, i.e. infrared-absorbing ability, of the gas as well as the rate at which it decays from the atmosphere. A GWP is calculated over a time interval of typically 20, 100 or 500 years.

Hydrocarbon (HC) Chemical compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms. Hydrocarbons such as propane and isobutene can be used as refrigerants. They have no ozone-depleting potential and very low global warming potential.

Hydrochlorofluorocarbon (HCFC) HCFCs are halocarbons containing only hydrogen, chlorine, fluorine and carbon atoms. Because HCFCs contain chlorine, they contribute to ozone depletion and they are also greenhouse gases. HCFCs were used as intermediate replacements for CFCs, but they are being phased-out by the Montreal Protocol and will be entirely banned as of 2030.

Hydrofluorocarbons (HFCs) HFCs are halocarbons containing only carbon, hydrogen and fluorine atoms. Because HFCs contain no chlorine, bromine or iodine, they do not deplete the ozone layer, but like other halocarbons they are potent greenhouse gases. Consumption of HFCs is growing world-wide, due to their function as replacement substances for CFCs and HCFCs.

Ozone depletion potential (ODP) A relative index indicating the extent to which a chemical product may cause ozone depletion compared with the depletion caused by CFC-11. Specifically, the ODP of an ozone depleting substance (ODS) is defined as the integrated change in total ozone per unit mass emission of that substance relative to the integrated change in total ozone per unit mass emission of CFC-11.

Refrigerant A fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects it at a higher temperature and a higher pressure of the fluid usually involving changes of the phase of the fluid.

1. Introduction

The fact that a significant share of food produced today spoils before it can be consumed, or even before it reaches consumers, is a great concern for food producers and consumers alike. It is estimated that post-harvest losses currently account for 30% of global food production, while less than 10% of the world's perishable foodstuffs are currently being refrigerated (Coulomb, 2008). The International Institute of Refrigeration (IIR, 2009) estimates that improving access to refrigeration in developing countries could prevent the spoilage of up to 23% of perishable foods currently produced in these countries.

In contrast to developed countries, where sophisticated cold chains are a routine occurrence, cold chains are highly underdeveloped or non-existent throughout most of the developing world. Most developing and emerging countries currently lack the basic infrastructure and management skills needed to support the development of integrated cold chains for distribution of perishable foods. In rural areas in particular, the handling, storage, transport, sale, and consumption of perishable food commodities often takes place entirely outside of temperature controlled environments.

According to the IIR (2009), just 19m^3 of refrigerated storage capacity are currently available per thousand inhabitants in the developing world, while for developed countries this figure stands at 200m^3. Where cold chain infrastructure is available, it is concentrated mostly in or around urban areas. In rural areas, where the 'first mile' of most food value chains is located and up to two thirds of overall food losses occur (Lipinski et al., 2013), functional cold chains are frequently absent.

The situation in developing countries is expected to be further aggravated over the coming years by a combination of factors. Rising temperatures driven by climate change are expected to cause an increase in refrigeration demand, while a continuing rapid population growth in developing countries, will increase the demand for food. With growing urbanisation, more and more people depend on well-functioning cold chains for their daily supply. Foodstuffs are mostly produced in rural areas or outside cities. Within urban areas foodstuffs are often channelled through distribution centres, shops and markets requiring constant temperature control.

Improving the cold chain coverage for food value chains has the potential to provide significant development benefits. By expanding the access to suitable infrastructure and strengthening local management capacities, environmental, economic and social gains can be achieved (figure 1).

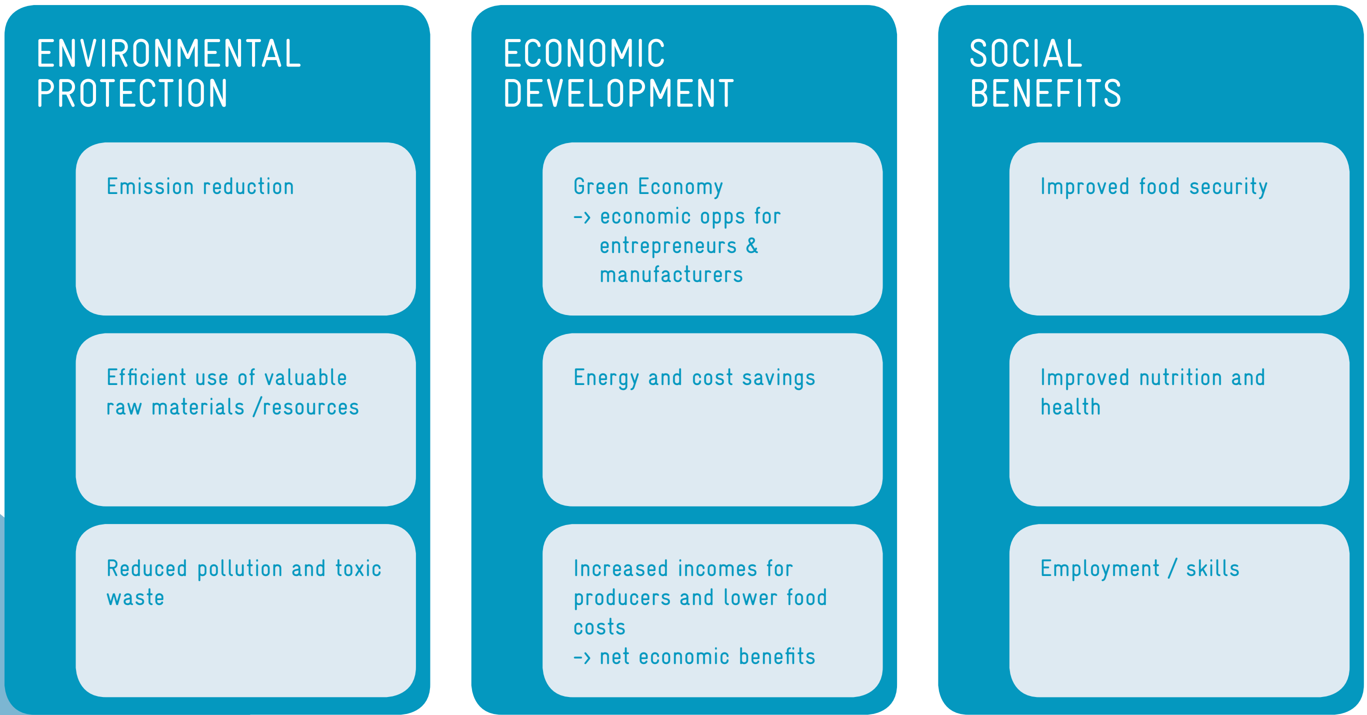


Figure 1: Environmental, economic and social benefits from improving food cold chains

2. The cold chain of food products

The purpose of the food cold chain is to maintain products in a consumable state. If consumption takes place immediately after production, a cold chain may be irrelevant, but as time passes, the likelihood of a food product perishing increases. The role of the cold chain then is to prolong the suitability of the food product for human consumption.

The length of cold chains may vary considerably, depending on circumstances. An example for a short cold chain could be a domestic refrigerator in which a household stores self-produced goods (e.g. milk). A full length cold chain comprises all aspects from post-production storage (small- or large-scale), through intermittent transport to retail, up until end-user refrigeration. The importance of a full length cold chain increases with distances and time passed between production and consumption. In particular large distances between the point of production and the point of consumption require constant temperature control to avoid unnecessary food waste.

Applying refrigeration to perishable produce in a timely manner is essential for obtaining tangible benefits. The decay of perishable foodstuffs sets in immediately after their production. If refrigeration is not applied in time, produce may decay to a point where the use of cold chains to prolong a product's shelf life is no longer feasible. For some highly perishable foodstuffs, such as dairy products, a window of opportunity during which the use of cold chains can provide a significant improvement in product shelf life may only exist during the first few hours after production.

Just like any other chain, the cold chain is only as strong as its weakest link. If the cold chain is interrupted, suffers major delays, or produce suffers physical damage due to inadequate handling, a cold chain's beneficial impacts on product shelf life and quality can be jeopardized as a whole. For highly perishable produce, exposure to high temperatures for as little as one hour can reduce shelf life by a full day (Fox, 2014). Maintaining the integrity of a cold chain is therefore essential to harness its benefits.

2.1. The "standard" Cold Chain

Kitinoja (2013b) defines the cold chain for perishable foods as "the uninterrupted handling of the product within a low temperature environment during the postharvest steps of the value chain including harvest, collection, packing, processing, storage, transport and marketing until it reaches the final consumer".

Food cold chains may vary significantly, depending on the local context. After production, some food products may be distributed directly to the consumer (e.g. on farm-sales). Where this is the case, produce might not require cooling. If time between production and consumption increases, however, produce should be handled within a continuous cold chain. Figure 2 demonstrates the relevant steps involved in this process. A cold chain does not necessarily have to entail all of the steps depicted in figure 2, but must entail at least one of the following elements:

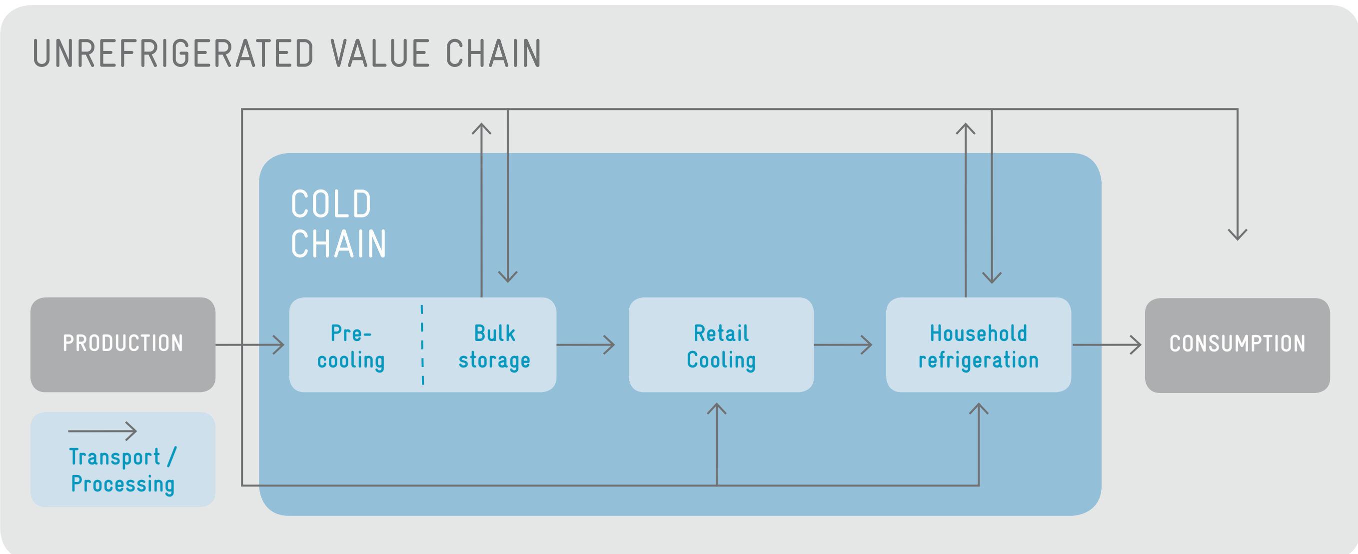


Figure 2: The unrefrigerated and the refrigerated path from food production to consumption

- ***Bulk Cooling***: Bulk cooling refers to the storage of (large) quantities of produce, which commonly occurs following the production and initial post-production handling. Bulk cooling may take place on farm, at production facilities, at collection/grading centres, or at processing facilities. Applying pre-cooling to a product prior to bulk cooling can help to achieve desired temperature reductions faster than direct integration into bulk storage.

- ***Retail Cooling***: Retail storage refers to the short-term storage of produce during marketing. Products need to remain visible to customers, which limits technologies and designs. Maintaining the temperature of smaller batches of produce generally is more difficult, compared to large batch sizes, due to a greater susceptibility towards the heat influx from ambient air (James and James, 2010).

- ***Domestic Cooling***: At household level, too, food should be kept within temperature regulated environments. Some households do without domestic cooling, as they immediately consume the products they purchase but most store food products for short periods of time. Domestic cooling is characterised by low or very low storage volumes and the mixed storage of various types of produce at identical conditions.

- ***Transportation***: When considering a cold chain, it is important that intermittent transport is also taken into account. This can take various forms and includes anything from reefer trucks to isolated plastic bags at the very last stage. Refrigerated transport is commonly designed to maintain low product temperatures, relying largely on insulation and effective control of airflow to do so. Transport refrigeration capacity is usually insufficient to cool warm produce to storage temperatures (Fox, 2014).

While ideal storage conditions vary considerably between different types of produce, the following three factors must be considered in any cold chain:

- ***Temperature***: Achieving and maintaining the product specific lowest suitable temperature (lowest safe temperature). Where safe temperature levels for a product are not adhered to, this will result in chilling or freezing injury and increased food losses.

- ***Humidity***: Providing for a relative humidity in the storage environment that prevents water loss and corresponding loss in weight and quality of produce, while also avoiding excess humidity. Excess humidity can also result from temperature fluctuations, causing water to condensate on product surfaces (sweating). Free water on the product surface can lead to favourable growing conditions for pathogens and therefore promote deterioration. Humidity is primarily influenced by the cooling technology applied, temperatures inside the storage space and airflows.

- ***Atmospheric composition***: The composition of the atmosphere within a storage space influences the rate at which metabolic processes, such as the ripening of fruit, progress. Metabolization in particular depends on the availability of oxygen. A simple way to exert influence on atmospheric composition within storage is the control of airflow (i.e. limiting or increasing the influx of outside air). More advanced methods include modified atmosphere packaging.

2.2. High-Income Countries (HICs) and Low-Income Countries (LICs) – A comparison

Whereas in industrialized countries cold chains are generally well integrated, with management responsibilities concentrated among only few key stakeholders (typically large food processors and/or retailers)[1] cold chains are usually not contemplated as a self-contained process in developing countries, but addressed by different stakeholders selectively through more or less isolated actions. In these countries, food value chains are characterized by a high degree of fragmentation, with a large number of loosely organized, small-scale producers, and an often excessive involvement of middlemen. An individual farmer, for example, might identify the need for a chilled storage place for his vegetables, but has no influence on the subsequent transport or reselling structure. In fact, there are many different stakeholders involved and many unknown variables.

Even where cold chain infrastructure is available in LICs, the quality of the applied infrastructure and its management is often a concern. Existing cold chains rarely possess a level of integrity similar to the one that is standard in developed countries. Temperature fluctuations and straightforward breaks in cold chains are a common occurrence in developing countries (Kitinoja, 2013b). This poses severe limitation on the effectiveness and applicability of cold chains, most notably for frozen

1 Large producer organisations, wholesalers, or processing companies have their own warehousing, distribution infrastructure and contracts, specifications, and audits for farmers, processors and carriers.

goods, which require gapless cold chain handling and, in many cases, very low temperatures of - 20°C or below.

The following sections contrast typical conditions in high income countries and low income countries at various stages of the cold chain, identifying key drivers and barriers for well functioning cold chains. By doing so, they provide reasons for why the development of cold chains in LICs is currently lagging behind and provide potential starting points for improving the situation in these countries.

A. Production

Status in HICs

- Producers are well informed on the status of markets and developments likely to affect market prices and demand in the near future. The availability of this information allows producers to align their production with demand in a timely manner.

- Producers are embedded in distribution networks which are able to absorb large quantities of produce fast.

- Conditions during production and subsequent post-production handling of food (harvest, sorting, grading, etc.) are optimized to reduce unnecessary heat intake.

- Food production is considerably less fragmented than in developing countries and higher average production quantities allow individual producers to own and operate storage facilities.

Status in LICs

- Food production is highly fragmented, with a large share of food producers engaging in subsistence agriculture.

- Average production quantities and individual producer's bargaining power are low.

- Producers often lack the necessary information on market prices and/or demand to make informed decisions on adjusting production levels or switching to the production of alternate goods Distribution network and corresponding infrastructure is limited.

- Post-production facilities for the grading, sorting and packing of food produce are often unavailable.

B. Bulk Cooling

Status in HICs

- Large bulk storage facilities are used for longer term storage with close adherence to optimum storage conditions.

- Different foodstuffs are kept at their respective best conditions.

- Meat and animal produce are stored separately from fruit and vegetables and different types of fruit and vegetables are separated between, depending on their storage compatibility.

- Products are pre-cooled to optimum temperatures before entering storage.

- Regulations and industry standards, ensuring high levels of food safety and traceability, are well-established and widely enforced.

- Quality of food products has a vital influence on marketability. High quality produce can achieve significant price premiums.

Status in LICs

- Currently, bulk storage of food products in developing countries rarely occurs under refrigerated conditions.

- The "first mile" of the cold chain, including post-production handling, bulk cooling and transport of food products is particularly underdeveloped in developing countries. Underlying reasons among others include the lack of infrastructure (including power grids) and distributed, low volume production.

- Some refrigerated collection facilities or warehouses are available, usually managed by producer organisations, wholesalers or processors. These are typically closer to urban centres and connected to grid electricity.

- Particularly during the initial "first mile", refrigerated storage facilities in developing countries are often comparatively small. The average total costs per m3 of storage capacity are therefore much higher as compared to large scale cold storage facilities.Operators and processing staff along cold chains are often insufficiently skilled to properly operate and maintain cold chain equipment which results in unnecessary food and energy losses (for instance when cold room doors are opened more often than required).

- Producers and handlers of food often lack an understanding for product specific ideal storage conditions and basic principles of temperature management. It is furthermore common for a variety of foods to be kept under uniform conditions without adjusting conditions on the basis of those products most susceptible to take damage. Available storage is frequently used to store amounts beyond its capacity, causing physical damage to produce and restricting airflow between goods.

- Food safety regulations are often either absent, unknown to producers, or unenforceable in practice. As a result, even unhygienic or unsafe produce may still be marketed, even if only at considerably reduced prices.

- Food quality has a limited influence on marketability, as parties involved often lack the knowledge or means to thoroughly assess food quality beyond sensory testing (looks, smell, taste, etc.). As a result, price premiums for high quality foods are low or even non-existent in most markets.

C. Retail cooling

Status in HICs

- Food is commonly sold in supermarkets or large retail outlets, which use large amounts of electricity to power elaborate refrigeration and air-conditioning systems.

- Storage times are reduced through marketing with e.g. special offers on products that are going to perish soon.

- Modern open display cases render products visible to customers, while ensuring energy efficient operation.

- Different products are kept at different temperatures.

- Retailers apply sophisticated supply chain control and management procedures to ensure quality standards are being met. Established standards for traceability of food products help retailers to provide targeted quality feedback to their suppliers to induce an improvement in product quality.

Status in LICs

- Street vendors and markets are the most prevalent point of sale for most food products in developing countries.

- Marketplaces often show a complete absence of cooling facilities or, indeed, even shade or wind protection for produce. Where shade is available, it is mostly used to keep vendors and customers cool (Kitinoja, 2010). Under these circumstances, open markets and street vending are prone to incur high rates of product deterioration and water loss.[2]

- Products are displayed to customers in open storage systems, where they are susceptible to sun and wind, resulting in increased product temperatures and water losses.

- Food retailers are often only in direct contact with middlemen. They have limited or no knowledge of the food producers involved in their supply chain. As food safety regulations are often absent or insufficiently enforced in these countries, it becomes very difficult for retailers to trace procured food products back to their respective origins and exert effective supply chain management/quality control.

D. Domestic storage

Status in HICs

- In developed countries, access to household refrigeration is the norm. There are approximately 63 household refrigerators per 100 inhabitants (IRR, 2009).

- Food is often purchased in bulk and stored at home for reasons of convenience (time saving) as well as to reduce costs.

- Food has a high quality when purchased, which allows for extended periods of domestic storage.

Status in LICs

- Access to household refrigeration is far less common than in developed countries. There are currently only about 7 household refrigerators per 100 inhabitants in developing countries (IRR, 2009).

- Food is purchased in low quantities by households to fulfil immediate needs.

2 Kitinoja (2010) reports an 11% weight loss in just six hours for leafy vegetables sold under open market conditions in Rwanda.

CASE STUDY

SOLAR POWERED COLD ROOMS FOR FRUIT AND VEGETABLES GROWERS IN NIGERIA

Mostly no cooling facilities are available at local Nigerian wet markets where products from small-scale farmers are sold. Furthermore, there is a lack of suitable refrigeration appliances. Especially in rural areas the electricity supply is unstable if present at all, complicating the use of conventional cooling technologies. Available cold rooms often run with diesel motors causing GHG emissions and unaffordable high operation costs. Moreover, climate harmful refrigerants which have a high GWP are used. Adequate cooling appliances would drastically reduce the share of crops which decay before being sold. In Nigeria, an average of 5% of vegetables and 35% of fruits is lost after harvest.

The project aims to enable Nigerian farmers to cool their harvested fruits in an energy-efficient and climate-friendly solar powered cold room. It will set up refrigerated storage facilities which are environmentally sound (energy efficient and in combination with natural refrigerants), cost efficient (affordable for farmers) and socially beneficial (through reducing income losses). The unit consists of the cold room with internal ice storage, a refrigeration unit, a secondary fluid circuit, battery power electronics, a PV generator and a shading roof. In case of deficient sunshine a small back up battery is sufficient to ensure energy supply. The average temperature will be from 5°C to 7°C. 200 kg of new fruits could be easily cooled down on daily basis. Through the use of natural refrigerants and renewable energy preventing GHG emissions the project will contribute to climate protection. Furthermore, it will lead to women empowerment and enhanced food security.

- When bought, food is often already too deteriorated to allow for meaningful domestic storage Key challenges towards the adoption of household refrigeration include affordability and awareness, as household refrigeration typically does not contribute towards value creation and incurred benefits tend to be long term and intangible in nature (e.g. improved health).

- Household level access to high quality andreliable sources of energy is often severely limited.

E. Transport

Status in HICs

- Well insulated and refrigerated transport vehicles (reefer trucks or vans) allow for close adherence to optimum storage conditions during transport.

- Advanced logistics management and use of ICT allow for efficient matching of supply with demand and on time delivery.

- A widespread, well maintained network of highly developed transport infrastructure promotes efficient and timely delivery.

- Availability of high quality, standardized packaging minimizes risks of damage to produce and load shifting during transport.

Status in LICs

- Unrefrigerated transport still accounts for the largest part of food transport in developing countries.[3]

- Even large transport infrastructure like air- and seaports sometimes lack the capacities to ensure uninterrupted cold chains. A particularly problematic issue,

3 In India, for example, less than 4% of fresh produce is transported under refrigerated conditions, compared to a share of around 85–90% in developed countries (Fox, 2014).

however, is the transport between production sites and collection or processing facilities (low production volumes, often widely distributed, often large number of intermediaries in supply chain).

- In rural areas in particular, transportation fees are sometimes determined on a per unit basis instead of by weight. The resulting incentive to increase the number of food products per transport unit has detrimental effects on product quality (physical damaging of produce, insufficient ventilation space, etc.).

- Time is a key variable in both refrigerated and unrefrigerated transport. Related challenges in developing countries are:

  - Deficiencies in logistics management, design of storage facilities and packinghouses frequently impede efficient product flow (Kader, 2009).

  - Inadequate transport (lack of reliable motorized transport).

  - Inadequate infrastructure which leads to increased transportation times, load securing issues (risk of physical damage to produce, shifting loads which reduced overall cooling efficiency), and increased risk of damages to cooling systems and frequent leakages.

CASE STUDY

EMISSIONS MITIGATION IN THE TRANSPORT REFRIGERATION SECTOR THROUGH THE INTRODUCTION OF INNOVATIVE LOGISTICS AND SUPPLY STRUCTURES IN SOUTH AFRICA

South Africa's economy depends largely on the sectors agriculture and trade where transport plays a vital role. Currently, there are about 14 000 trucks and trailers in the refrigerated transport sector. In terms of their direct greenhouse gas emissions, each cooling unit of the truck contains refrigerants, mainly the hydrofluorocarbon blend R404a, which has a global-warming potential (GWP) of 3922 and to a lesser extent the hydroflourocarbon 134a (HFC-134a), which has a GWP of 1430 times that of CO_2. Furthermore, the refrigeration unit and truck engine consume fuel and therefore create indirect emissions in the form of CO_2. These indirect emissions contribute less than 50% in smaller trucks, but up to 75% in trailers.

The project aims to contribute to the climate-friendly development of the transport refrigeration sector in South Africa through two main interventions: changing to natural refrigerants, such as hydrocarbons, with less global warming potential, and reducing the energy consumption of the cooling and transportation process through energy efficiency improvements. The project further supports the South African government to integrate the transport refrigeration sector into their national mitigation strategy.
Estimated emission reductions due to improved insulation are around 15 t CO_2 per year per trailer and around 10 t CO_2 per year per truck. Through the use of R290, compared to R404A, the COP can be increased by up to 27% at -20°C and up to 28% at 0°C. The refrigeration charge can be reduced significantly from 3,5 kg to 0,65 kg and total emissions are reduced from 11,8 t CO_2-eq to 4,0 t CO_2-eq.

2.3. Challenges and Recommendations

Challenges

- Cold chains are complex, integrated systems, comprising of a series of distinct steps, which can be geographically dispersed and tend to involve a variety of different stakeholders. Shortcomings on any segment of the chain can endanger the positive potential impact of the cold chain on product shelf life. Absence or non-application of regulation and standards for food quality and traceability prevents effective supply chain management (i.e. in the form of targeted support for suppliers) by supply chain champions.

- The large number of middlemen often involved in food value chains in developing countries can significantly affect the viability of introducing and maintaining cold chains. The resulting fragmentation of the value chain, involving a large number of stakeholders, constitutes a hindrance towards the development and financing of necessary cold chain infrastructure as well as effective cold chain management.

- In most instances, the economic viability of cold chains in large part depends on the occurrence of price premiums, which can translate improvements in product quality into noticeable economic benefits. Realization of such premiums, however, strongly depends on the ability of buyers and consumers to assess product quality, as well as both their ability and willingness to financially reward it.

- Operators and processing staff along cold chains are often insufficiently skilled to properly operate and maintain cold chain equipment which results in unnecessary food and energy losses (for instance when cold room doors are opened more often than required, or recommended refrigerant levels are not maintained).

- Adhering to the defined storage capacities is essential for cold storage to be effective. Insufficient spacing between storage walls and produce or stacks of produce, ultimately preventing cold air from reaching and cooling down the produce, is a common source of error in small scale cold rooms. When doorways, aisles and circulation space are taken into account, commonly only about 60% of a cold room's floor space remain available for the storage of goods (Kitinoja and Thompson, 2010).

- Circulation is also affected by product packaging. Where produce is packed too tightly, in too large quantities, or materials used do not allow for cold air to reach the produce, the efficiency of cold storage is significantly impeded. Unsuitable packaging can cause physical damage to produce, further reducing its quality and shelf life.

- For small-scale producers and other small businesses, maintaining short-term cash flow is often crucial to sustaining business operations. In the absence of suitable forms of finance, this negatively impacts on their ability to invest into cold storage as well their ability to use existing cold storage in order to compensate for short-term price fluctuations (i.e. short term storage of produce in anticipation of increasing prices). Economic benefits associated with greater flexibility regarding time of sales / greater bargaining power can thus often prove difficult to achieve in practice.

- Average operating costs for bulk storage tend to be significantly higher in developing countries.[4] Reasons for this discrepancy include the geographical dispersion of producers, small land holdings and a lack of uniformity in cropping, which result in the need to establish multiple, small farm gate collection centres 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.

- Another key challenge relating to the economic viability of bulk storage in developing countries is the often highly pronounced seasonal variation in production volumes for a number of foodstuffs (see also 3.). Cooling infrastructure may therefore be used only during short peak seasons. Where this is the case, a reduced ROI and longer payback periods are the consequence.

4 A study conducted in India on behalf of GIZ suggests that operating costs for controlled atmosphere cold storage in India amount to approximately US$ 60/m^3/year, which is almost twice as much as in similar European facilities (Pullenkav, 2016).

Recommendations

- In order to effectively address food losses, cold chain interventions need a thorough understanding of local value chains and translate selective action into a comprehensive overall approach. In order for cold chain interventions to make real sense, they must either connect to existing cold storage infrastructure, which is typically situated in or around urban areas, or suitable markets (consumer or wholesale markets). Isolated interventions, which are unable to ensure linkages to existing cold chains, food processing, or adequate target markets will almost certainly fail to achieve social and economic benefits.

- In planning cold chain interventions[5], the identification of suitable target markets for refrigerated produce should occur early on. Projects should make it a priority to ensure that produce reaches markets which allow for higher quality and/or refrigerated goods to achieve price premiums. Where local markets do not allow for price premiums to be paid, alternative marketing routes should be considered. Failure to do so can threaten economic viability.

- Maintaining an uninterrupted cold chain requires access to infrastructure such as roads, electricity and water supply. These aspects should therefore be considered during the value chain analysis and any assessment on cold chain improvement potentials. The use of GIS-based planning tools, comprising data on transportation and utility networks, coupled with information on producer clusters and market locations, may lead to better informed decision-making in identifying intervention 'hot spots'.

- Successful implementation of cold chain interventions requires an inclusive approach towards stakeholder engagement and involvement. Despite their sometimes ambivalent role, any outreach and extension efforts should also aim to involve middlemen, as they possess a potential key role in the adoption of cold chains. For an overview on key stakeholders throughout the cold chain, see Annex II Stakeholders.

- Quality management considerations and supply chain control are important drivers of cold chain development. In the absence of suitable regulation and standards on food quality and traceability, finding alternative means to increase transparency across value chains and establishing linkages between involved actors are key considerations for the adoption of sustainable cold chains. This could, for example, be achieved by shortening value chains ('cutting out the middlemen'), organizing stakeholders, e.g. via producer collectives, or formalizing relationships between the stakeholders involved in a value chain.

- Financial mechanisms for the procurement of appliances should be investigated. For domestic appliances, credit facilities are sometimes already quite well established and offered directly by appliance retailers at prime plus interest rates. Cooperation with such retailers could make domestic appliances more affordable. On the levels of bulk and retail cooling, the choice of appliances may be more limited and more specialised, but these appliances are nonetheless internationally readily available. Business planning support to assess the feasibility of investments could greatly support enterprises dependent on bulk and retail cooling. Furthermore, energy technology providers (such as photovoltaic system retailers and suppliers) already incorporate both expertise and products regarding efficient and cost-effective cooling options. Thus, a combined energy and appliance solution can be pursued to provide comprehensive cold chain solutions. This is an important consideration for financial institutions who are generally reluctant to enter into technology risks, without necessary guarantees, warranties and after-sales-service support from private industry.

5 Approaches and tools for the analysis of agricultural value chains, such as the ValueLinks methodology (for the newest version see International ValueLinks Association e.V., c2016) or the Rapid Loss Appraisal Tool (RLAT) for agribusiness value chains (GIZ, forthcoming), can provide suitable starting points and guidance for planning cold chain interventions.

- Establishing cold chains should always include capacity building for the staff involved at all stages of the cold chain to ensure optimal and sustainable operation of cooling technologies. The establishment and operation of cold chains require specialist knowledge and skills in a number of areas, including general awareness and knowledge of the effects of temperature on food products, product specific storage requirements, good practices in the handling and packaging of food products, skills required for the operation of cooling technologies, as well as business and supply chain management and logistics.

3. Food products and their demand for cooling

Each type of perishable food product has a specific storage potential related to its physiological nature. The use of the cold chain can help to reduce food losses for perishable produce. Inappropriate application of cooling, on the other hand, may lead to higher food losses. For example, freezing is necessary for transporting fish and seafood especially over long distances, but inadequate for some sorts of fruit and vegetable.

To provide safe and palatable food products of high quality, attention must be paid to every aspect of the cold-chain and any interruption has to be prevented. Failure of understanding the needs of each product (see table 1) results in reduced shelf life, deterioration in product quality, increased losses and/or unnecessarily high energy consumption. Health risks are equally important. Cooling reduces the rate at which microbiological, physiological or biochemical changes occur in food. Several studies have shown that food poisoning in many countries is affected by seasonal changes, with a higher incidence in hot (humid) summers and fewer cases during cold winters, as high temperatures favour the survival and proliferation of microbes, leading to increased contamination of food, and increased risk of infection. (Bentham, 2002; Hall, D'Souza and Kirk, 2002, Charron et al., 2005).

Cooling contributes towards extending the shelf life of perishable foods and improving food quality by:

- Reducing respiration --> lessens perishability.
- Reducing transpiration --> lessens water loss and shrivelling.
- Reducing ethylene production and increasing resilience towards ethylene --> Delays ripening and natural senescence.
- Decreasing activity of micro-organisms --> decreases the rate of decay.
- Reducing browning and loss of texture, flavour and nutrients.

As a rule of thumb, food degradation processes increase two- or even threefold with every 10°C increase in temperature (Kitinoja, 2013a). In other words, reducing storage temperatures by 10°C will double the shelf life of a perishable food product.

FOOD TYPE	RELATIVE PERISHABILITY AND MAXIMUM SHELF LIFE	IDEAL TEMPERATURE RANGE	IDEAL RELATIVE HUMIDITY	IDEAL ATMOSPHERIC COMPOSITION
FRUIT AND VEGETABLES	Low – medium perishability: Max. shelf life can vary considerably, ranging from two weeks up to several months	Approx. 0°C to 2°C for none chilling sensitive crops Approx. 5-15°C for chilling sensitive crops	Fairly low – very high: Ranging from approximately 70% to close to 100%, but usually high to avoid water losses Most fruit 85% to 95% Most vegetables 90 to 98%	Remove oxygen from storage atmosphere and increase CO_2 content to decrease rate of metabolic processes
DAIRY	High perishability: Fresh milk max. storage life up to two weeks	Around 4°C for fresh milk Approx. 10°C-12°C for cheese	Low – medium, to avoid microbial growth on surfaces	For ethylene sensitive produce, avoid ethylene build-up to slow ripening
FISH AND MEAT	Very high perishability: Max. storage life of up to one week for meat and 10-15 days for fish	Meat approximately -2°C to 4°C Fish approximately 0°C to 2°C	Medium – high, to avoid water losses: Meat approx. 85%-95% Fish generally above 90%	Atmospheric composition is of low relevance for storage of most dairy products

Table 1: Overview on the storage needs of different food products

3.1 Fruit and vegetables

General perishability varies widely among horticultural produce. Maximum achievable storage life ranges from under two weeks for high perishability produce (e.g. ripe tomatoes, leaf lettuce) to up to several months for long-lasting fruit and vegetables (e.g. apples). Perishability is largely influenced by a crop's water content, vulnerability or softness of tissue, and respiratory activity.

Optimum storage temperatures, too, vary widely. Most crops are best kept at temperatures close to their respective freezing point (-2°C to -0.5°C) and up to 2°C, while chilling-sensitive crops, mostly tropical/subtropical fruit and vegetables, require storage temperatures in the range of approx. 5 to 15°C (Kader, 2013).

If temperatures are allowed to fall below safe temperatures, this may result in chilling damage, reduced shelf-life and quality loss. Exposure to alternating cold and warm temperatures can result in sweating (moisture accumulation on the commodities surface), which in turn enhances decaying processes.

Fruit and vegetables are highly susceptible to water loss and therefore generally require a high humidity environment. Optimum relative humidity values for different types of horticultural produce range from approximately 70% to close to 100%, whereby values for most fruit range from approximately 85% to 95% and those for most vegetables from approximately 90 to 98% (Kader and Rolle, 2004). Fresh fruits and vegetables are live products which continue to respire and metabolize. Metabolic processes can be inhibited or stimulated by controlling the availability of oxygen within the storage atmosphere. Metabolization leads to heat discharge, which has to be accounted for in determining the cooling demand of fruit and vegetables.

Some fruit and vegetables produce ethylene, a colourless hydrocarbon gas, as they begin their ripening process. Ethylene works as an aging hormone in plants. Ethylene in the storage atmosphere will accelerate fruit ripening processes, thus reducing the potential shelf life for ethylene sensitive crops.

The large variation among optimum storage conditions for fruit and vegetables[6] can pose a barrier towards the storage of different crops in one storage space. What is more, recommendations on storage conditions for one crop are often erroneously applied to other crops as well (Kitinoja, 2013a), causing damage to stored produce and negating the overall purpose of cold chains.

6 For a collection of storage recommendations for a broad range of fruits and vegetables, see University of California, Davis (2015).

CASE STUDY

SOLAR-POWERED COLD STORAGE FOR THE BULK STORAGE OF FRUIT AND VEGETABLES IN INDIA

In India, food losses of fruit and vegetables across the entire value chain from producers to consumers currently amount to about 40% of the production. A key driver for these high food losses is the lack of appropriate cold chain infrastructure. As of now, cold storage is only available for approximately 10% of India's perishable produce. Existing cold storage facilities are situated mostly in close proximity to urban centers. Cold storages are only available for approximately 10% of India's perishable produce. Where cold chain infrastructure is in place, it is often designed solely for the storage of potatoes.

The project aimed at providing a holistic approach to help vegetable famers in the Nadia district of West Bengal to overcome the main barriers they face in the production, storage, transportation and marketing of horticultural goods. The approach sets out to link the establishment of cold storage facilities with improvements in production and post-production handling of vegetables, towards the backend of the value chain, and to an improved approach for the transport and marketing of goods, towards the front-end of the value chain. The Installed facilities aggregate approx. 2000 kg of horticultural produce per day, from a pool of over 1000 farmers; so far, over 400 MT of agricultural produce have been processed. Agricultural produce should be graded and sorted before being introduced into the cold chain. To maximize economic benefits, cold storage should be used for high quality (grade A or B) produce only.

CASE STUDY

FIELD TESTING OF AN INNOVATIVE, SOLAR POWERED MILK COOLING SOLUTION IN TUNISIA

The region of Sidi Bouzid, in central Tunisia, is responsible for approximately one sixth of the national milk production in Tunisia. Under the given climatic conditions, milk can exceed the maximum bacterial count prescribed by Tunisian food safety laws after about two to five hours. During the hottest periods of the year, lack of quality is the most common reason for the refusal of milk at collection centers. Furthermore, due to low production volumes, evening milk collection is not available year round, thus causing additional on-farm losses. The project supports the field assessment of a solar-powered milk cooling solution, designed to meet the refrigeration needs of small and medium-sized dairy farmers in developing countries, in Sidi Bouzid, Tunisia. The ice-based cooling solution was developed specifically to overcome the challenges during short-term on-farm storage of milk and transportation to collection centers.

The milk cooling solution is based on the commercially available Steca PF 166 DC refrigerator, with a modified control unit. The modifications allow the refrigerator to function as a smart solar freezer, by adjusting its operation to the availability of solar energy. The freezer has a volume of 166l and is capable of producing approx. 8-13 kg of ice per day. The system comes with 25 reusable ice tins of 2l capacity and two 30l isolated milk cans with removable ice compartment. To cool down 30l of milk from 36°C to 15°C in one of the supplied milk cans, the systems needs 6kg of ice and approx. one hour. The smart solar freezer is powered by 600Wp solar PV modules. Due to the application of a 120 Ah battery and thermal energy storage (PCM - ice), the system is able to run autonomously for up to 7 days during periods of low solar radiation and high ambient temperatures.

3.2 Dairy

High perishability is a key constraint of dairy production in developing countries. This is largely due to microbial growth, for which fresh milk provides a near perfect environment. Even at optimal temperatures of around 4-6°C, untreated milk can only be stored for a maximum of two weeks, whereas at temperatures of around 30°C, milk will spoil within a few hours after production (Kitinoja, 2013b). Humidity should be kept low, to avoid wet surfaces which promote microbial growth. Hygiene is absolutely essential for the entire dairy cold chain. The degree of seasonal variability in dairy production, resulting mainly from variations in the availability of feedstock for cattle, can be very pronounced in developing countries.[7]

Processing generally plays an important role for dairy products, although the share of processed vs. unprocessed dairy varies greatly between countries. The most common form of processing for milk is pasteurization, during which milk is heated to kill off a share of the contained microorganisms, before being cooled down again to storage temperatures. Alternative forms of processing include cheese making. Storage conditions for cheese depend on type of cheese, but temperature typically ranges from 10°C-12°C, at a relative humidity of approximately 80%-90%.

7 In Senegal, 80% of the milk production is produced during just two months of the year (Knips, 2006).

3.3 Fish and meat

Enzymatic processes causing muscle tissue to mature, and, above all, bacterial growth makes meat and fish highly perishable food products. Even at optimal storage conditions, fresh fish has a maximum storage life of 10 to 15 days (Kitinoja, 2013b; Cengel and Ghajar, 2015). For unprocessed meat, refrigerated storage is limited to about one week (Cengel and Ghajar, 2015). Due to its inclination to microbial growth, poultry is of particularly high perishability. This process is highly temperature dependent, with certain bacteria doubling their count in 1h at 25°C, compared to 36h at -2°C (Cengel and Ghajar, 2015).

Optimum short-term storage temperatures for fresh meat range from approximately -2°C to 4°C, while fish is best kept at 0-2°C (Cengel and Ghajar, 2015). For longer term storage of several months to up to two years, produce must be kept frozen. Both meat and fish are susceptible to water loss and are best kept at a high relative humidity. The appropriate range for meat is approximately 85%-90%. For fish relative humidity should generally exceed 90% (Cano-Muñoz, 1991; Cengel and Ghajar, 2015).

Preservation of fish should begin on-board the fishing vessel, immediately after the catch. In some cases, animals are kept alive, while in others fish is introduced to the cold chain by putting them on ice or into cold water. Due to similar storage conditions, different kinds of meat or fish can generally be stored in the same storage space. Common processing methods to enhance the storability of fish and meat include drying, smoking and curing.

CASE STUDY

APPLICATION OF A SOLAR-ICE MAKER FOR THE REFRIGERATION OF FISH IN SENEGAL

Fishers in Félane – and similar, small remote fishing villages – arrive at night at their harbors. The next morning, the catch needs to be delivered to Foundiougne where wholesalers from Dakar will pick it up for further transportation and selling. Under the given climatic conditions, fish and marine products deteriorate at a high rate which reduces both the lifespan of the product and the ability for fishermen to obtain good prices for their catch. Therefore, the catch needs to be consequently cooled during its nightly storage in Felané and transportation to the local market in Foundiougne. The fish wholesaler bring ice produced in Dakar to Foundiougne using it exclusively for their own transportation. Only one on-grid ice factory is available in Foundiougne to meet the cooling demands of the local markets. However, the transportation and storage of ice does not work properly and the ice never arrives at the places where it is actually needed.

The PERACOD project finances and supports the technical set-up of the ice machine, which is operated by a women,'s co-operative. In the piloting phase, ice was sold in 20 Liter buckets (~ 10 kg) to Félane fishers for 1000 FCFA (1,5 €) each. The key customers are fishermen originating from Félane, but fishers from other villages close-by may also buy ice produced by the co-operative.

3.4 Challenges and Recommendations

Challenges

- Knowledge of and close adherence to product specific cooling requirements and optimum storage conditions is key to reduce food losses and realize cold chain benefits. Ignorance of these requirements and faulty application of cooling can cause significant damage to food products.

- In rural areas in particular, knowledge about the effects of temperature on food, or even familiarity with temperature specifications expressed in Celsius or Fahrenheit are often lacking.

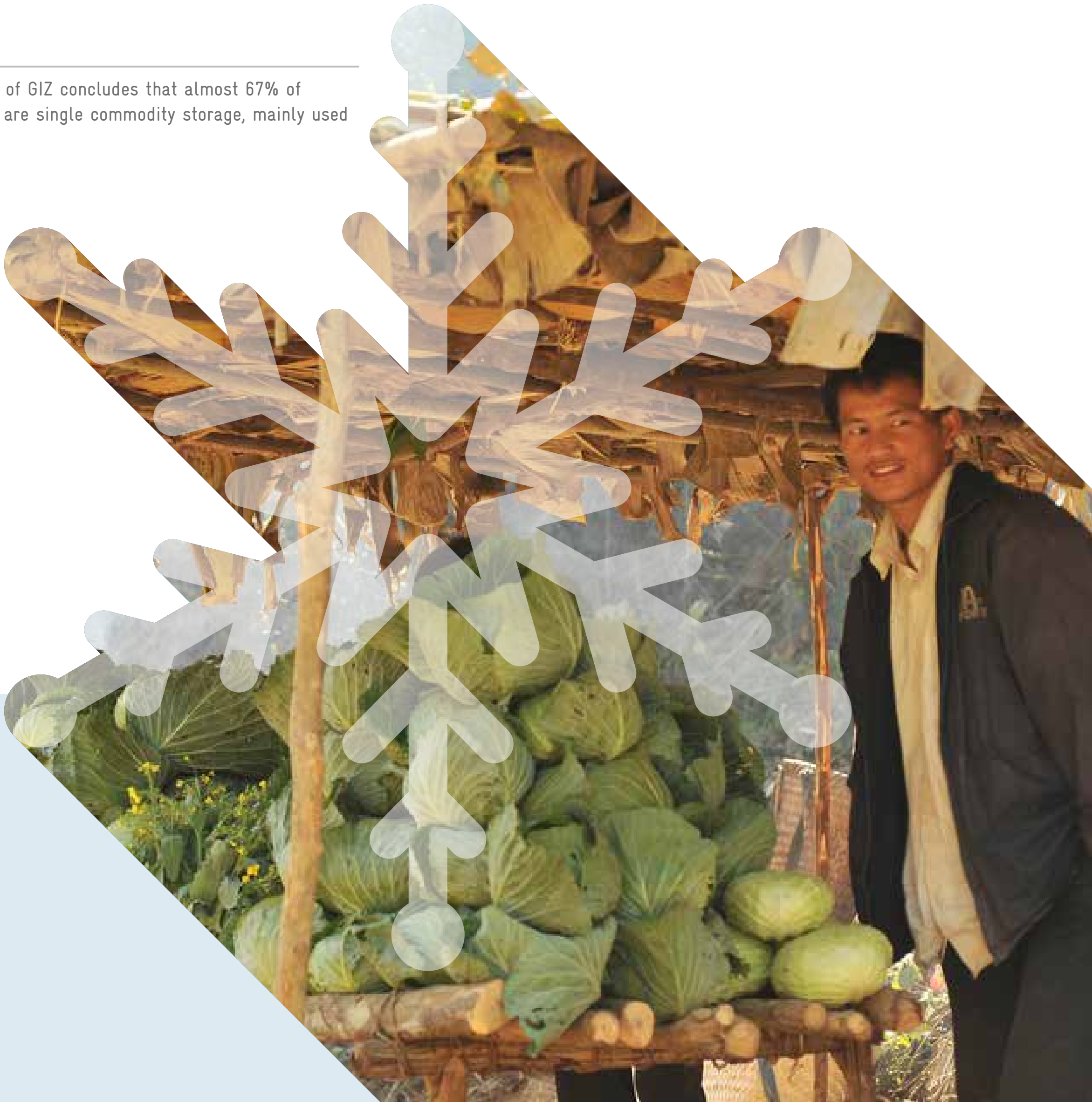
- Cooling requirements and optimum storage conditions vary greatly among food products, both between and sometimes within food categories. For multi-purpose cold storage, determining storage compatibility and upholding it in practice can be challenging. Thus, where cold storage infrastructure exists, it is currently often designed for and used only to store a single commodity.[8]

8 A study conducted on behalf of GIZ concludes that almost 67% of existing cold storages in India are single commodity storage, mainly used to store potatoes.

Recommendations

- Effective implementation of cold chains requires knowledge not only of cooling technologies, but also of specific storage characteristics of food products as well as the principles and benefits of temperature management and good practice in food handling more generally. Cold chain related projects need to incorporate these aspects into awareness raising and training activities, to ensure a correct application of cold chains. Simplified controls, featuring presettings for various food products, or remote monitoring applications can help to reduce complexity in the operation of refrigeration systems.

- Food products should be graded and sorted before being introduced into cold chains. Subjecting only higher grade produce to cold chain treatment, while selling slightly damaged and lower grade produce locally, without previous cooling, can prove more feasible and economically viable. Where possible, projects should therefore seek to encourage the establishment of modern facilities for grading, sorting and packing alongside cold storage infrastructure.



4. Cooling Technologies

Along the cold chain, a large variety of cooling technologies are available today. They differ in key performance characteristics, such as output temperature ranges, energy and refrigerant use, as well as capital and operational costs (see table). The characteristics of a cooling system will firstly depend on the cooling method applied (vapour compression, ab-/adsorption, evaporative cooling, cooling through the use of ice) and secondly on the make and model chosen. Identifying the most suitable technologies for a given context can therefore be an intricate task, which requires specialist knowledge and data collection in a number of areas.

In general, the removal of heat for the purposes of chilling or freezing foods is energy intensive and as such has the potential to generate substantial greenhouse gas emissions. In addition, halogenated refrigerants, which are frequently applied in cold chain systems, possess a very high global warming potential and in combination with typically large leakage rates of up to 50%, further contribute towards greenhouse gas emissions. Whilst the application of refrigeration systems helps societies to fight hunger and increase economic development, they can thus be counterproductive regarding their impact on climate change. Thus, it is important to choose technology solutions that are least harmful to the environment. Ideally, refrigeration systems need to be based on so-called green cooling technologies, which combine maximised energy efficiency and natural refrigerants and have least impact on the climate.

4.1 Available Technologies

A variety of different technologies are available to meet the cooling needs at various stages of the food cold chain. According to the cooling method applied, one can differentiate between vapour compression systems, ab-/adsorption systems, evaporative cooling systems, and cooling through the use of ice (ice makers). These technologies differ significantly with regards to a range of key performance and operational characteristics, such as output temperature range, energy and refrigerant use and primary areas of application (see table 2).

In the following, a more detailed description of the working principles, primary areas of applications and other key characteristics are provided for each of the above mentioned technologies. In addition, Annex III Cooling Technologies: Selected examples contains selected product examples of cooling technologies currently available or under development.

COOLING METHOD	PRINCIPAL APPLICABILITY				OPERATING ENERGY	REFRIGERANT USE
	FOOD PRODUCTS	TEMPERATURE RANGE	COLD CHAIN STEPS	OTHER		
VAPOUR COMPRESSION CYCLE	All food products	Full temperature range (incl. freezing)	Entire cold chain		Electric	Halogenated or natural refrigerants
SORPTION	All food products	Full temperature range (incl. freezing)	Entire cold chain, but limited applicability in transport		Thermal	Natural refrigerants
EVAPORATIVE COOLING	Chilling sensitive fruit and vegetables	Temperatures of above 10°C	Mainly bulk storage, household refrigeration	Climatic limitations (low humidity)	Thermal (passive)	Water
ICE-MAKING	Non-chilling sensitive produce only, mainly fish and meat	Temperatures around 0°C	Entire cold chain		Electric or thermal	Halogenated or natural refrigerants

Table 2: Key characteristics of different cooling technologies

4.1.1 Vapour compression

The vapour compression refrigeration cycle is the most widely applied method in commercial refrigeration and air-conditioning technologies. Vapour compression cooling relies on an electricity driven, mechanical compressor. It is therefore also known as mechanical refrigeration. A liquid refrigerant is circulated and exposed to low and high pressures successively. In a low pressure environment, the refrigerant evaporates while absorbing heat from its environment, thus providing a cooling effect. Subsequently, the gaseous refrigerant is compressed, condensed and so returns to its liquid state, while rejecting the heat to the previously absorbed heat to its environment.

Basic applicability

- Vapour compression refrigeration is applicable across the full temperature range (including freezing), rendering this cooling method suitable for most any cooling application.

- The method provides for medium to high relative humidity storage environments, mostly in the range of 80%-90%.

- The small size cooling unit allows for variety of applications, including household size refrigerators and mobile applications, e.g. in reefer trucks or vans.

- Its reliance on mechanical parts (compressor) makes vapour compression high maintenance compared to alternative cooling methods, although this applies primarily to larger refrigeration units above 10kW.

- During operation, systems can produce significant noise and vibration, the latter of which can cause refrigerant leakage.

Energy use

- Vapour compression systems operate on electricity. Comparatively high Coefficient of Performance (i.e. ratio between refrigerating capacity and power consumed).

Refrigerant use

- Use of halogenated or natural refrigerants.

- In developing countries, in part due to their low costs and much greater availability, vapour compression based refrigeration systems primarily rely on halogenated refrigerants.

Costs

- Vapour compression cooling systems are characterized by lower initial investment costs compared to other conventional forms of cooling, especially where standard air conditioner units are used, but high running costs.

- For a small cold room, with commercially installed vapour compression refrigeration system, construction costs lie at around 7,000 USD for 3.5 kW (1 ton) of refrigeration capacity and about $8,500 for 7 kW (2 tons) of refrigeration capacity (in US prices) (Kitinoja and Thompson, 2010); system costs do, however, strongly depend on whether cold room is pre-fabricated or owner built, new or used.

- DC fridges and freezers for use in rural and low-income households or retail are often significantly beyond affordable levels. In Ghana, the market price for a 12V/24V DC vapour compression chest fridge or freezer lies in the range from 1100€ to 1800€, with a further 800€ of material costs required for standalone solar-PV operation (Glaser, 2012).

4.1.2 Sorption cooling

Sorption cooling units are less widely applied than vapour compression systems. Adsorption cooling in particular currently exhibits a low degree of commercialization, with a limited number of specialist applications in existence to date.

The refrigeration process is thermally driven and based on physical/chemical attraction between a working pair of substances, a refrigerant and an ad-/absorbent. When subjected to a low pressure environment, the refrigerant will evaporate at ambient temperatures. The occurring evaporation absorbs heat from its environment, thus creating a cooling effect. Once evaporated, the gaseous refrigerant is attached to or absorbed by the ad-/absorbent (adsorption or absorption, respectively). Thereby pressure is reduced in the evaporator, allowing for more refrigerant to evaporate. Thermal energy is used to evaporate the refrigerant out from the ad-/absorbent and restore original conditions.

Basic applicability

- Similar to vapour compression systems, sorption cooling systems can provide output temperatures across the full temperature range, including freezing.
- Primarily low/medium relative humidity.
- Generally large system size (especially adsorption) tends to limit applicability with regards to smaller household, commercial and transport refrigeration applications.
- Compared to vapour compression higher system complexity but lower maintenance due to little or no moving parts and significantly reduced risks of refrigerant leakage.
- Adsorption is a naturally intermittent process, in which cooling is followed by a recharging phase. To achieve a continuous cooling effect, systems require multiple adsorbent beds.

Energy use:

- Sorption cooling systems operate on thermal energy, with little to no electricity required, depending on design.
- Use of low-grade thermal energy makes systems highly flexible in terms of energy sources.
- Most common are use of solar thermal energy (e.g. evacuated tube or parabolic trough collectors) or waste heat (industrial processes, or even exhaust heat from internal combustion engines).
- The intermittent nature of the adsorption process allows for storage of thermal energy with very low losses.
- Application of hot fluid storage tanks allows for extended thermal energy storage.
- Flexibility in terms of energy sources, low or no reliance on electricity and energy storage potential have made sorption systems a popular choice for standalone applications under intermittent or off-grid conditions, where little or no electricity is available.
- Coefficient of Performance (COP) achieved by sorption cooling systems is significantly lower than for vapour compression systems.

Refrigerant use

- Sorption cooling systems rely on natural refrigerants.
- For absorption cooling ammonia-water or lithium bromide-water combinations are most common.
- Adsorption systems mostly use silica gel-water or zeolite-water working pairs. In addition to being climate friendly, these substances are also non-flammable and non-toxic.

Costs:

- Sorption cooling systems are characterised by higher capital costs and very low operating costs due to their use of low grade thermal energy and low maintenance requirements.
- Adsorption is still very expensive compared to conventional cooling technologies and mainly used for specialist medical refrigeration applications; unless technological advances or economies of scale reduce costs significantly, they are unlikely to be viable for food cold chains in the short term.

4.1.3 Evaporative cooling

Evaporative cooling utilizes the cooling effect resulting from the evaporation of water. Water is applied to a porous surface (e.g. sand or charcoal). As temperatures increase, it begins to evaporate. As water undergoes a phase change from a liquid into a gas, it absorbs energy in the form of heat from the surrounding air, thus cooling it. This simple cooling method only requires water as a coolant, running freely over a porous surface, and, since the process is driven by heat from the surrounding environment, requires no additional energy. However, the cooling process can be sped up by using fan-assisted systems.

Basic applicability

- Evaporative cooling is limited in its applicability by certain physical limitations. The lowest possible temperature that can be reached through evaporative cooling lies approximately 1° to 2° C above the so called wet-bulb temperature 9. A low wet bulb temperature requires a low relative humidity. The temperature range achievable through evaporative cooling strongly depends on local climatic conditions.

- Technologies based on evaporative cooling are most effectively applied in semi-arid climates, while being largely ineffective in humid climates. Even under favourable conditions, however, temperature reductions of more than 10-15°C below ambient temperatures are unlikely to be achievable.

- Due to its inherent dependence on ambient conditions, the technology does not allow users to adjust temperatures in order to meet product specific temperature requirements.

- Evaporative cooling produces high relative humidity storage environments.

- The technology is suitable primarily for non-chilling sensitive fruit and vegetables, especially tropical or sub-tropical crops. It is not suitable for produce requiring low storage temperatures, or produce prone to microbial growth like dairy products, fish, or milk.

- Evaporative cooling systems are low-tech, robust systems, which can be manufactured with limited prior knowledge.

- Requires continuous supply of reasonably clean water in sufficient quantity and therefor might require suitable water pumping technology and water storage reservoirs.

- Water quality is critical in terms of maintenance intensity. 'Hard water', with high concentrations of calcium and magnesium, will cause the build-up of scale deposits on the cooling ribs and will, over time, significantly reduce the cooling effect, unless removed regularly. To avoid the formation of such deposits as well as the occurrence of unhygienic conditions associated with bacterial growth, evaporative coolers have to be overhauled or replaced regularly (in most instances approximately every 3 to 5 years).

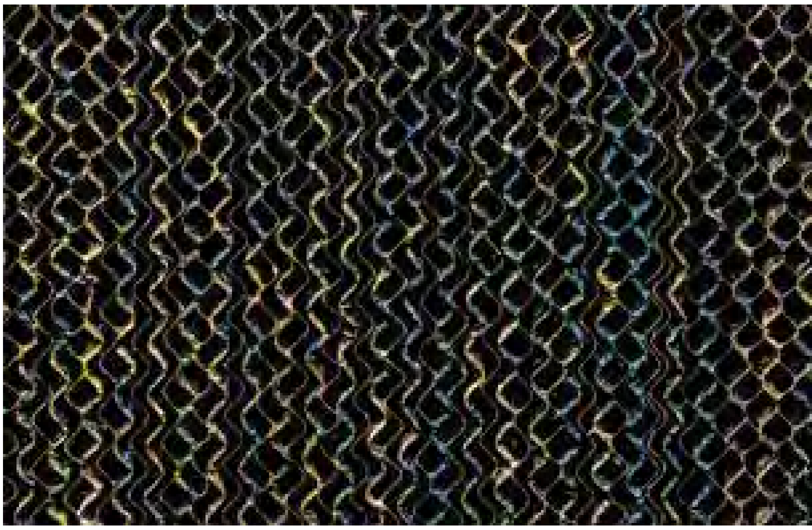
- Evaporative cooling is applied primarily applied for small walk-in cold rooms, commercial and household units. Transportable systems are available.

Energy use

- Evaporative cooling requires no energy input to operate, if pressurised water flow is available.

- Systems do, however, require frequent water refills/wetting of surfaces.

- Where electricity is available, user comfort and cooling efficiency can be improved by installing electric water pumps and/or fans.



9 The wet bulb temperature defines the lowest possible temperature that can be achieved through evaporation of water under given climatic conditions. Its value varies between locations and over time, depending on climatic conditions.

- In such instances, a 12-24V power supply is generally sufficient. During operation, these systems use approximately 0.7 kWh per ton during pre-cooling or 0.07-0.12kWh per ton per day during cold storage (Kitinoja and Thompson, 2010).

Refrigerant use

- Evaporative cooling solely requires water to operate.

Costs

- Potentially low cost compared to conventional cooling applications, provided water pumping and piping is provided.

- In most cases units can be manufactured/constructed locally, but overall system planning and installation could be more complex due to water availability criteria.

- Hence, system prices can vary considerably depending on local costs of labour and materials.

- In India, for example, a small evaporative cooling chamber with a capacity of 100-200kg can be built for as little as 1 USD per kg of capacity, while prices for similarly sized units; in Ghana or Tanzania are between 4 and 6 times higher, respectively (Kitinoja, 2010).

- For commercially sized units (6 tons or above), the cost of water pumps and fans has to be accounted for. In 2009, suitable solar-powered exhaust fans (including PV panel) were available for approx. 400 - 600 USD (Winrock International, 2009).

4.1.4 Ice-making

Ice can be applied in the cooling of food products in two ways. Firstly, it can be applied directly to produce / packaging including the produce in the form of top-ice cooling or by adding ice to water in which a product is then submerged (as a form of hydro-cooling). Secondly, ice can be kept in an ice bank or ice battery to cool down the air around stored produce through convection (natural or fan assisted).

Ice can be made on the basis of any cooling technology suitable for freezing. Most commonly either vapour compression systems or absorption cooling, with ammonia-water, or lithium bromide-water working pairs, are applied.

Basic applicability

- Storage temperatures around 0°C, unsuitable for chilling sensitive produce.

- Mostly applied in cooling dairy, meat and fish.

- Various forms of ice available for different applications (chipped ice / flake ice, nuggets, block ice, etc.).

- Limited precision temperature control (typically via controlling the amount of ice added).

- Slow freezing (i.e. freezing at temperatures slightly below 0°C) poses a potential risk to product quality.

- Where ice is used in direct contact with produce, its applicability is limited to water tolerant produce or the use of waterproof packaging. The latter incurs additional costs.

- Melting of ice can cause sanitation problems, by creating an environment conducive to the growth and spread of microbial pathogens.

- Very short cooling times of 0.1h - 1h: Highly suitable for initial heat removal (pre-cooling).

- Requires clean water / water treatment to reduce risk of contamination of produce.

- Transportability is a major advantage of ice. One centrally located facility with a reliable source of energy can provide ice to surrounding homes and businesses, even if they lack energy supply. This allows for transport cooling and flexible business models in which "cold" can be sold centrally and moved to consumers within a certain range.
  On the downside, transport of ice is limited in range. This is particularly the case, where well-insulated containers are not available. This is very likely to be the case were ice is sold in small quantities to a large number of consumers. In such instances, a large share of the cooling potential will be lost to the environment.

Energy use

- Ice-making requires energy only during production cycles, while using no energy during standby phases.

- Allows for different freezing methods and a variety of energy sources to be used.

- Most commercial icemakers produce roughly 5-12 kg of ice per kWh, while some highly efficient icemakers achieve an output of about 18.5 kg of ice per kWh. Pre-cooling of 1 ton of produce by 28°C requires about 330 kg of ice. This makes for an energy use of between 28 kWh to 66 kWh per ton for standard commercial units and about 18 kWh per ton for high efficiency applications (Winrock International, 2009).

- Ice is a suitable storage medium for cold, if sufficiently insulated storage space is available. Without proper insulation, ice storage is subject to high losses and low efficiency.

- For renewable energy-based electric systems in particular (such as photovoltaics or wind chargers) ice-making can act as a form of energy storage during times of high energy resource availability, which reduces the required battery-storage capacities.

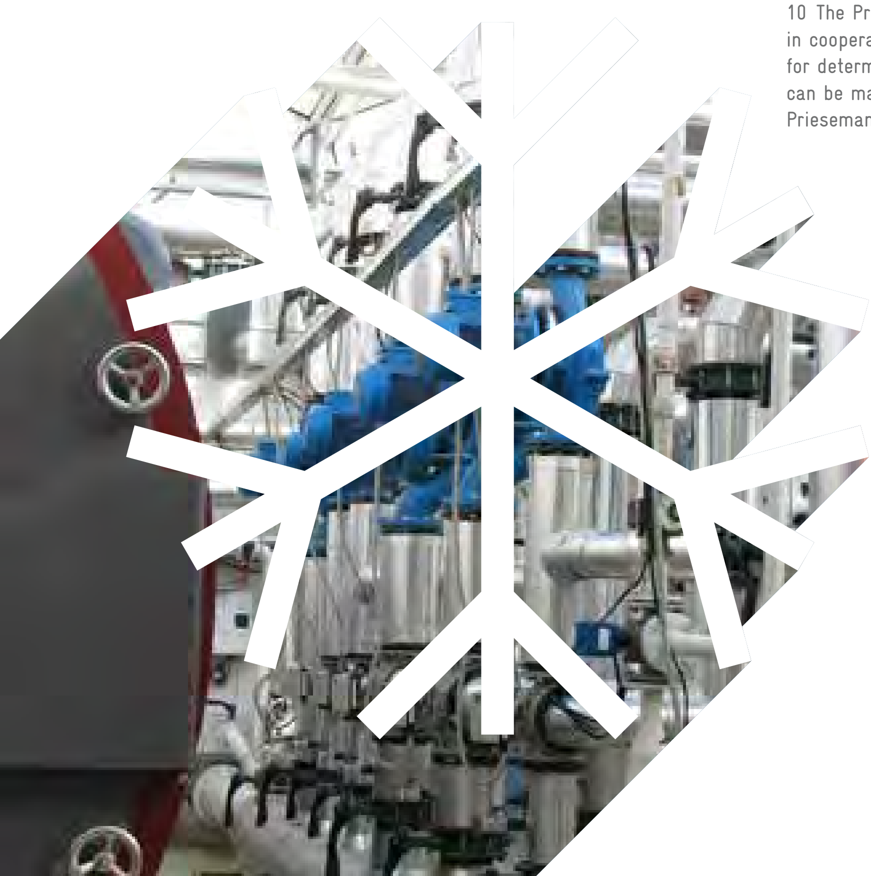
Refrigerant use

- Use of halogenated or natural refrigerants.

Costs[10]

- The costs of ice-making are closely linked to the costs of vapour compression or sorption units used to provide cold.

- In general, vapour compression cooling units are characterised by lower capital investment costs and higher running costs, compared to absorption systems.



10 The Promotion of Least Cost Renewables in Indonesia (LCORE-INDO) in cooperation with ILK Dresden have developed a calculation model for determining the economic feasibility of solar ice-making. This model can be made available to interested parties upon request to Caspar Priesemann (caspar.priesemann@giz.de).

4.2 Applicability of cooling technologies according to food product

	FRUIT AND VEGETABLES	DAIRY	FISH AND MEAT
VAPOUR COMPRESSION REFRIGERATION	**Medium** Highly variable temperature range: Suitable for chilling-sensitive and non-chilling-sensitive produce Most suitable for high value produce Comparably low humidity can cause high water losses	**High** Optimum temperature within range High value produce Insensitive to low humidity	**Medium** Optimum temperature within range and freezing possible High value produce Comparably low humidity can cause high water loss
SORPTION COOLING	**Medium** Highly variable temperature range: Suitable for chilling-sensitive and non-chilling-sensitive produce Most suitable for high value produce Comparably low humidity can cause high water loss	**High** Optimum temperature within range High value produce Insensitive to low humidity	**Medium** Optimum temperature within range and freezing possible High value produce Comparably low humidity can cause high water loss
EVAPORATIVE COOLING	**Medium** Temperatures above 15°C: Mostly suitable for tropical/sub-tropical crops Requires tolerance for very high relative humidity Low cost solution, suitable also for low value produce	**Very low** Temperature range of above 15°C, significantly above optimum Inclined to microbial growth: High temperatures and high humidity unsuitable	**Very low** Temperature range of above 15°C, significantly above optimum Inclined to microbial growth: High temperatures and high humidity unsuitable
ICE PRODUCTION	**Low** Most crops sensitive to low temperatures (chilling or freezing injury)	**Medium** High perishability produce, requiring low temperatures Melting poses contamination risk Suitable for produce in water-proof containers (primarily milk)	**High** High perishability produce, requiring low temperatures Produce non-sensitive to water and high humidity preferable Melting poses contamination risk Transportability of ice allows for use on fishing vessels

Table 3: Applicability of cooling technologies across different product categories

	BULK COOLING	RETAIL COOLING	DOMESTIC COOLING	TRANSPORT
VAPOUR COMPRESSION REFRIGERATION	**High** Highly variable temperature range Variety of systems commercially available High maintenance	**Medium** Variety of systems commercially available Limited applicability in open markets Moderate system and high running costs Requires high quality power supply	**Low** Household size systems widely commercially available Prohibitively high system and running costs Requires high quality power supply	**Medium** Units for trailers/vans widely commercially available Requires continuous energy supply (typically diesel engine) Auxiliary diesel units often very low in energy efficiency Susceptible to refrigerant leakage
SORPTION COOLING	**High** Variable temperature range Commercial size systems available Suitable as standalone system in off-grid location	**Low** Very high system cost High complexity and large system size Requires high quality power supply	**Very low** Prohibitively high system cost High complexity and large system size Requires high quality power supply	**Low** Intermittent process suitable for energy storage (i.e. no energy source required during transport) Solid adsorbents insus-ceptible to leakage Very high system cost Few mobile applications available Portable applications typically require re-charge after each use
EVAPORATIVE COOLING	**Medium** Simple, potentially low cost Can be built from various materials, with-out prior knowledge Highly suitable for off-grid locations No running costs Applicability and effectiveness limited by climatic factors Severely restricted temperature range Requires continuous supply of clean water	**Medium** Simple, potentially low cost Can be built from var-ious materials, without prior knowledge Highly suitable for off-grid locations No running costs Available in various sizes, portable or fixed Applicability and ef-fectiveness limited by climatic factors Severely restricted temperature range Requires continuous supply of clean water	**High** Simple, potentially low cost Can be built from var-ious materials, without prior knowledge Highly suitable for off-grid locations No running costs Temperature range suit-able for most fruit and vegetables Applicability and ef-fectiveness limited by climatic factors Requires continuous supply of clean water	**Medium** Simple, potentially low cost Requires frequent water refills Increased airflow through movement speed can impair cooling Requires continuous supply of clean water
ICE PRODUCTION	**Low** Allows for external or collective ownership of expensive cooling equipment Restricted tempera-ture range and limited precision temperature control Only suitable for non-chilling sensitive produce Slow freezing can incur damage to products Requires well insulated storage	**Medium** Allows for external or collective ownership of expensive cooling equipment Allows for open display Only suitable for non-chilling sensitive produce Restricted temperature range and temperature control unsuitable for storing different foods in shared space Low in convenience – requires continuous supply of ice	**Low** Allows for external or collective ownership of expensive cooling equipment Requires well insulated storage Temperature range unsuitable for many household products Low in convenience – requires continuous supply of ice	**High** Low costs compared to standard transport cooling technologies No on-board energy source required - suita-ble especially for small vehicles or transport without vehicles Requires well insolating packaging Limited range, unsuita-ble for longer distances

Table 4: Applicability of cooling technologies across the cold chain

4.3 Refrigerants

Refrigerants are substances that are used to transfer thermal energy from the cold part of a refrigeration system to the hot part where the heat is rejected to the surroundings. The thermodynamic and other properties of a refrigerant are fundamental to their use. One can distinguish two main categories of refrigerants, synthetic halogenated refrigerants and natural refrigerants.

4.3.1 Halogenated refrigerants (CFCs, HCFCs, HFCs)

Synthetic substances used as refrigerants are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs). These halogenated refrigerants have to be chemically synthesized as they do not occur in nature. CFCs have been and HCFCs are being phased out under the Montreal Protocol. They have been controlled by the Montreal Protocol since 1987 because of their ozone depleting potential. Consumption of HFCs, however, is growing dramatically world-wide due to their function as replacement substances for CFCs and HCFCs. Nevertheless HFCs are strong greenhouse gases, whose use should be avoided. Unsaturated HFCs (u-HFCs, also marketed as hydrofluoroolefins, or “HFOs”) are synthetically made HFCs with no ozone depleting potential (ODP) and low global warming potential (GWP) that have been developed specifically to fulfil regulations that prohibit HFCs with higher GWP (e.g., above 150). Some are slightly flammable and combustion can form hydrogen fluoride. In the atmosphere, their decomposition leads to the formation of trifluoroacetic acid (TFA), a strong acid, toxic to some organisms. There is no known degradation mechanism for TFA, which therefore remains as a persistent waste within the atmosphere, water and biosphere.

4.3.2 Natural refrigerants

Natural refrigerants are climate friendly. They have a very low or zero global warming potential and zero ozone depletion potential. They are part of the natural biogeochemical cycles and do not form persistent wastes in the atmosphere, water or biosphere. Natural refrigerants are the naturally occurring substances CO_2, ammonia, water, air and hydrocarbons such as propane, isobutane and propene. Production of these substances to refrigerant-grade is only a fraction as energy intensive as for fluorinated refrigerants. Natural refrigerants are widely used in some refrigeration and air-conditioning (RAC) applications, for example isobutane in domestic refrigerators and ammonia in large cooling systems, such as industrial refrigeration facilities. Natural refrigerants are relatively cheap because they are mass produced for a wide range of uses and are readily available, where distribution structures are established. Natural refrigerants can often be sourced as by-products from other processes. Recycling or disposal after use in cooling systems is easier than with CFCs, HCFCs and HFCs.

All natural refrigerants have characteristics that require additional safety measures, compared to conventional CFCs, HCFCs and HFCs. Both hydrocarbons (HCs) and ammonia are flammable, while ammonia is also corrosive and of higher toxicity. Simple measures such as the use of appropriate materials, the selection of safe components and technician training can offset the risks resulting from these undesirable characteristics.

BULK STORAGE	RETAIL STORAGE	DOMESTIC STORAGE	TRANSPORT
For walk-in cold rooms and refrigerated warehouses, halogenated refrigerants are most common (e.g. HCFC-22 and HFC-410A for larger capacities, or HFC-134a for smaller units) Natural alternatives are hydrocarbons (e.g. HC-290, HC-600a, or HC-1270) for small and medium scale solutions and CO_2 or ammonia for larger refrigerated warehouses In particular for tropical fruit and vegetables, evaporative cooling can provide a water based alternative	Most supermarket and grocery stores are still using HCFCs and HFCs as refrigerants Supermarkets in Europe, however, are increasingly switching from fluorinated gases to natural refrigerants with favourable thermodynamic properties to increase energy efficiency For refrigerators and single open display boxes, hydrocarbons like HC-290, HC-1270 or HC-600a provide natural refrigerant alternatives	The use of Isobutane HC-600a is global standard and commonly used in more than half of all domestic fridges globally. Greenpeace (2009) claims that there are over 400 million hydrocarbon refrigerators in use today and that of the 100 million domestic refrigerators and freezers produced annually worldwide between 35% and 40% of the production now use hydrocarbons.	Most commonly used refrigerants are synthetic (HFC-134a, HFC-404A, HFC-410A, Short-term replacement R-452A) Natural alternatives include, hydrocarbon refrigerants (HC-290 or HC-1270), R290, R744 or liquid CO_2, or N_2 (cryogenic) Refrigerant leakage is a common problem, in particular under difficult road conditions

Table 5: Refrigerant use throughout the cold chain

CASE STUDY

CONVERSION OF SUPERMARKET REFRIGERATION SYSTEMS FROM F-GASES TO NATURAL REFRIGERANTS IN SOUTH AFRICA

Before the project started, all supermarket refrigeration systems in Southern Africa operated on fluorinated refrigerants with high ozone depleting and/or global warming potentials. The project components aimed to demonstrate and promote the complete conversion from F-Gases to natural refrigerants in supermarket cooling facilities. The installation of the two pilot refrigeration systems led to a wide acceptance and further replication of the new technology in South Africa and other African countries. The new refrigeration system runs with Ammonia (R-717) in the compressors and uses a heat transfer medium for the distribution into the cold rooms and cabinets in the trading area. A CO_2 cascade provides the temperatures needed for the freezer cabinets. Monitoring results so far confirm that in the two supermarkets energy savings of 19-26% are achieved. Generally, the implementation of natural refrigerants could safe 1000-2000 t CO_2 emissions annually. Maintenance costs for natural refrigerant systems and conventional systems are comparable while some savings of up to 4000 to 5500 ZAR (South African Rand) annually per natural refrigerant system could be achieved due to lower cost for refrigerant refill. Through the project the first indirect cooling system in a supermarket in South Africa was implemented. Presently, quite a few new supermarkets like the company Makro S.A. are choosing to apply indirect systems using CO_2 in a cascade for low temperature. Pick n pay itself will introduce cooling systems relying on natural refrigerants in 25 other supermarkets and aims to convert all of its supermarkets.

4.4 Challenges and Recommendations

Challenges

- Technologies using the vapour compression cycle are by far the most widely available today. Alternative technologies, such as adsorption systems, in contrast, mostly are at an early stage of market development. Zeolith-water-adsorption systems in particular have a range of interesting properties for a potential application in remote, off-grid areas. At current production levels, however, high unit prices limit their use to high value medical and vaccine storage. Without further market development and taking advantage of economies of scale, these innovative technologies are likely to remain far too expensive for widespread application in food cold chains.

- The range of technologies currently available for transport cooling is fairly constrained. Most solutions available to date rely on vapour compression systems powered by small auxiliary diesel generators. In addition to often being fairly inefficient (these systems account for up to one fifth of overall diesel use during transport), their use is, for the most part, restricted to expensive reefer vans or trucks. As a result, costs for refrigerated or chilled transport remain high and transportation constitutes one of the key bottlenecks for cold chains in developing countries.

Recommendations

- With few exceptions (see above), the development of cooling technologies suitable for application in developing countries is well advanced already or at least well under way, with a limited overall need for support in this area. Instead, emphasis should be given to developing suitable business models for cold chain applications and promoting overall market development for such technologies.

- The choice of cooling technologies depends on a wide range of factors. At a minimum, the following should be taken into account:

  - The technologies compliance with product specific storage requirements, including lowest safe temperature, tolerance towards humidity, respiration rate and ethylene production of fruit and vegetables, etc.

  - Estimated product throughput (i.e. the amount of commodities that must be cooled within a given timeframe) and capacity utilization over extended periods of time.

  - Site specific conditions, such as ambient temperatures and temperatures of produce when introduced into cold storage, incident solar radiation, etc..

  - Availability of energy sources and required energy storage.

  - Presumed economic benefits (e.g. in terms of achievable price premiums for cooled and/or higher quality produce, or reduced losses) and availability of transport linkages to suitable target markets.

  - Balancing refrigerant characteristics, cost, and environmental responsibility.

  - Availability of suitable packaging to minimize the risks of physical damage or contamination of produce during the cooling process.

5. Energy for food cold chains

A high quality, stable and uninterrupted energy supply is crucial for successful cold chain operation. Power failures, voltage and frequency fluctuations, and other shortcomings in the energy supply at any stage can negate the overall viability of the entire chain. The lack of reliable and affordable energy throughout large parts of the developing world, and particularly in rural areas, poses a key barrier towards widespread adoption of modern cold chains.

An analysis conducted as part of this study suggests that in India average energy expenditure amounts to almost one third of total operating costs, a share approximately three times above the average levels in developed countries (Pullenkav, 2016). Although the share may differ in other countries, this example underlines the fact that energy expenditure currently accounts for a substantial share of cold chains' operating costs in developing countries.

Cooling is a highly energy intensive process. According to recent estimates, as much as 15% of the energy consumed worldwide today is used for refrigeration and air conditioning (both domestic and commercial) (Wang, 2014). Typically over 80% of the global warming impact of a refrigeration system are due to its energy use (Coulomb, 2006), although the exact share varies depending on the refrigeration technology applied, the system's energy efficiency and the refrigerant used.

5.1 Energy demand in food cold chains

The energy demand in food cold chains varies, depending on the technology applied. Vapour compression cooling systems currently provide the highest efficiency in terms of the ratio between refrigerating capacity and power consumed among available cooling technologies. Demand patterns, too, vary with the technology applied. Most cooling and refrigeration technologies require a steady supply of power, while others, most noticeably ice-making, may have significant standby intervals, during which little or no power are consumed.

Overall, the energy demand of food cold chains is influenced by a range of factors beyond the principle choice of a cooling technology and cooling unit size. The most important factors influencing energy demand in cold chain applications include:

- ***On-site climatic conditions*** in terms of temperatures, incident solar radiation, and, to a lesser degree, also wind speeds and humidity.

- ***Storage design characteristics*** in terms of insulation quality and basic storage design considerations (e.g. ratio of surface area compared to storage volume, surface albedo, exposure of storage to sun and wind, etc.).

- ***Produce related specifics***, including the type of produce to be stored, the temperature difference between products entering storage and their optimum storage temperature, as well as the actual storage volumes across prolonged periods of time (product throughput).

- ***Usage and behavioural aspects***, such as the frequency and duration of doors being opened (the single largest source of air infiltration in cold storages).

- ***Technological influences***, including dissipating waste heat generated from refrigeration system's operation, or electricity usage and heat dissipation of ancillary equipment such as lights and fans.

Energy demand in food cold chains is closely linked to the capacity utilization rate of cold storage. Among the above listed factors, produce heat load constitutes the single largest influence on the total refrigeration load and therefore on energy consumption. With the exception of storage conception and design, all of the described factors are subject to potentially significant daily or seasonal variations, which will more often than not depend on the actual utilization of an installed cooling solution in practice. The resulting large deviations in energy demand render accurate demand prediction difficult and potentially impede the economic viability of energy supply.

5.2 Energy supply

5.2.1 Electric systems

Electrically driven vapour compression refrigeration, also known as mechanical refrigeration, is the most commonly used technology for cooling applications today. The majority of developing countries' existing cold chain infrastructure is situated in urban/peri-urban areas, where existing power infrastructure ensures at least intermittent electricity supply. Unmet cooling needs, on the other hand, mostly concentrate on post-production handling, bulk cooling and transport during the "first mile". These processes are concentrated first and foremost in rural areas with limited and often unstable or even no grid electricity supply.

In areas without grid infrastructure, or low quality power supply and regular power failures diesel generators are often used as primary means of power generation, or power backup for times during which the grid is not operational. Despite a frequent and often significant subsidisation of diesel, operational costs for diesel systems are high and their use contributes to the high average energy expenditure for cold chains in developing countries.

Regarding the use of decentralized renewable energies, the following can be ascertained that in many countries solar PV and other renewable energies already provide an economically viable alternative to the use of diesel generators, which are typically used to ensure a reliable energy supply in off-grid or intermittent grid situations.[11] High capital costs for renewable energy technologies, however, can pose a significant barrier towards their adoption. In the absence of suitable financing options, most potential users have difficulties in obtaining the necessary starting capital, or simply prefer not to make large investment into renewable power generation, which they perceive as high risk.

When applying renewable energy sources such as solar PV, systems need to be designed to accommodate to the erratic power supply. An unstable energy supply requires the use of energy storage technologies or backup solutions. When using solar PV setups featuring DC to AC power conversion via inverters, providing the necessary power surge required on system start-up can be problematic.

11 This is for example indicated by results from two studies conducted on behalf of GIZ in Indonesia (Strobel, 2015) and India (Pullenkav, 2016).

5.2.2 Thermally driven systems

Thermally driven cooling applications (sorption cooling, evaporative cooling) provide for an alternative to mechanical refrigeration. These systems are considered, in particular where a reliable supply of electricity cannot be guaranteed, or sources of thermal energy, first and foremost waste heat, are readily available.

The working temperatures of thermally driven cooling solutions, and therefore the required energy input, vary according to the field of application and system design. Application of certain refrigerant working pairs or more complex multi-effect absorption processes, for example, can offer increased energy efficiency at higher operating temperatures of several hundred degrees. On the other end of the spectrum, sorption cooling applications for vaccines and off-grid uses are typically designed to operate on heat sources of about 100°C or below.

In principle, a wide range of energy sources qualify for the use in thermal refrigeration applications:

- ***Waste heat*** from food processing, such as the pasteurization of milk, or various other industrial processes.
- ***Solar thermal*** energy, harnessed through evacuated tube collectors, parabolic trough collectors or parabolic dishes, depending on the required working temperatures.
- Thermal energy from ***biomass*** or ***biogas*** incineration.
- Although low in overall energy efficiency, ***electricity***, too, can be utilized to provide energy for thermal cooling applications.

A majority of sorption cooling systems installed to date run on waste heat or solar thermal energy, which is mostly due to very low running costs and the high degree of energy independence that these power sources offer. In addition to thermal energy, most sorption cooling technologies do require small amounts of electricity to operate (e.g. for pumps in absorption systems, or valves and controls in most ab- and adsorption systems).

5.2.3 Energy storage

The ability to store energy cost-efficiently is crucial for the development of modern food cold chains under off-grid and intermittent grid conditions, where energy supply is otherwise too erratic to ensure the safe storage of food products. Where a high quality, continuous energy supply exists, energy storage can be a useful means to lower refrigeration costs, by enabling users to shift electricity consumption to off-peak hours. The two prevalent options in energy storage for cooling applications are electric batteries and thermal energy storage (TES).

Electric batteries are the most basic form of energy storage for cooling applications. Deep-cycle batteries are widely available and are commonplace in larger off-grid or intermittent-grid cooling installations. The most common types of electric batteries include lead-acid batteries, molten salt batteries, lithium-ion batteries, and flow batteries.[12]

Electric batteries are a simple and mature technology, with high market penetration to date. They incur only moderate initial investment costs, compared to thermal energy storage solutions. Nevertheless, for small commercial and domestic applications in particular, the use of electric batteries and the incurred costs for maintenance and replacement may have a significant influence on the total costs of a refrigeration system. Electric batteries are not applicable to cooling systems driven by thermal energy.

Most electric batteries require frequent maintenance and replacement. Depending on the type of battery used, the typical lifespan ranges between approximately 3 to 7 years. Lead acid batteries in particular suffer from a low Depth of Discharge (DoD) and as a result are prone to timely breakage if the designed depth of discharge is repeatedly exceeded. They are also subject to a reduced life expectancy when exposed to high ambient temperatures (typically above 25°C).

Due to their typically short average lifespans and the commonplace reliance on toxic or polluting substances, waste generation and potential environmental risks from improper disposal pose a further potential disadvantage for electric batteries, when compared to alternative forms of energy storage.

Thermal energy storage (TES) provides an alternative to the use of electric batteries. Available types of TES include the use of phase change materials, mostly in the form of ice depots, thermo-chemical energy storage, based on sorption processes, or hot fluid storage tanks (thermally driven cooling applications).[13] Several off the shelf cooling systems designed for off-grid application are equipped with thermal energy storage (mostly in the form of ice batteries).

Overall, TES possess a low market penetration to date, which results in a limited availability in most developing countries. Their higher overall complexity, demanding insulation requirements and often high material costs (especially advanced phase change and thermo-chemical materials) tend to imply higher initial investment costs compared to electric batteries. TES are of higher durability, require little to no maintenance, and achieve significantly longer average lifespans than electric batteries. Although strongly technology dependent, the approximate lifespan for most types of TES lies in the range of 7 to 15 years. Different to electric batteries, they are not susceptible to high ambient temperatures and their designed depth of discharge lies close to 100%, making them less likely to take damage during operation.

In principle, TES, with the exception of hot fluid storage tanks, are applicable to all types of cooling systems, whether they operate on electricity or thermal energy. Due to their comparably high costs, however, they are mostly suitable for larger cooling installations, although ice banks in particular can be an option for smaller commercial installations. Some types of TES, in particular thermo-chemical storage and hot fluid tanks, are suitable for the recovery of low grade waste heat recovery.

12 For a comprehensive overview on available types of batteries and the current state of battery technology see IRENA (2015).

13 A comparison between state of the art TES is available from IRENA (2013).

5.3 Energy efficiency

The energy consumption of refrigeration systems depends on several factors which lead to higher or lower energy efficiency:

- ***Technology***: Over recent years, several efficient technologies have evolved, including optimised compressor design, cost-effective inverter and other variable speed compressor drives, electronic expansion valves, advanced heat exchanger design, electronic controllers and certain designs of circuitry. Appropriate use of these technologies can more than double the efficiency of standard systems.

- ***Reduction in heat load***: Although the heat load is not necessarily related to efficiency, it directly affects the size of the refrigeration system, the amount of refrigerant used and the energy consumption. Techniques such as improved insulation, low energy ancillary equipment (fans, LED lighting, etc.) and working procedures can substantially reduce energy use.

- ***Refrigerant***: The efficiency of a system also depends on the refrigerant and its thermophysical properties. Some refrigerants are more suited for some applications and climate zones than others and therefore lead to higher efficiencies. Hydrocarbons (HC) for example have very good properties and systems with HC refrigerants are usually more efficient than the same units with fluorinated refrigerants. CO_2 is an excellent refrigerant in ambient temperatures below 30°C, but for now less efficient in hotter climates.

BULK STORAGE	RETAIL STORAGE	DOMESTIC STORAGE	TRANSPORT
Optimise components (e.g. compressor, heat exchanger) Use inverter technology coupled with an alternator to improve compressor part-load efficiency Use thermally driven solar chillers instead of electrical driven mechanical chillers, where such alternatives are available Maintain insulation in good condition, including door seals and strip curtains, which are worn down easily during cold storage operation Reduce heat influx through good management practices (e.g. adjusting production practices to reduce temperature of incoming produce, minimize opening of doors or number of persons in cooled space)	Optimise components (e.g. compressor, heat exchanger) Use inverter technology to improve part-load efficiency Retrofit open refrigerated supermarket display cases with transparent doors Recover waste heat from the refrigeration system to be used for store requirements	Reduce product throughput, e.g. by restricting usage to perishable foodstuffs as much as possible Size system appropriately and adhere to maximum capacities Make sure doors/lids close properly, e.g. by using systems with lockable doors Consider positioning of cooling system, so as to avoid unnecessary exposure to heat or wind and allow for generated waste heat to disperse Resort to evaporative cooling solutions where their cooling effect is sufficient	Optimise components (e.g. compressor, heat exchanger) Use inverter technology coupled with an alternator to improve part-load efficiency Use HC refrigerant with favourable thermodynamic properties Reduce leakage, as fully charged systems are more effective Reduce cooling needs by improving insulation of vehicle, optimising delivery routes, decentralising food distribution and proper handling of goods Optimise dimension of refrigeration unit based on size, insulation and use of vehicle Use of the correct temperature setting, since different foodstuffs require storage at different temperatures

Table 6: Increasing energy efficiency throughout the cold chain, some examples

5.4 Challenges and Recommendations

Challenges

- A high quality energy supply is crucial for any cooling or refrigeration application. Unexpected changes in energy availability and/or prices are among the most common sources of failure for cold chain projects in developing countries (Yahia, 2010; Winkworth-Smith et al., 2015).

- Energy demand for cold storages tends to vary considerably over daily and seasonal periods. The resulting deviations in energy demand render accurate demand prediction difficult and provide a potential barrier towards developing sustainable business models for supplying cooling applications with energy from decentralized, renewable sources.

Recommendations

- Standard cold storage design procedures often rely on steady-state heat loss and gain calculations under estimated peak demand conditions. By only providing a 'snapshot' of conditions at a certain point in time and neglecting the often significant variations in cooling demand over short (daily) and longer (seasonal) periods, characteristic for developing countries, these simulations create an insufficient picture of energy demand and resulting energy cost. To correctly assess these factors, dynamic demand simulations over extended periods of time should be applied, wherever possible.

- Site selection, storage placement and basic design, such as the placement of doors outside of main wind directions, can provide for 'low hanging fruits' in terms of a cold storage's energy efficiency.

- Projects need to incorporate the risks associated with potentially frequent and severe variations in energy demand in early stage planning and develop effective response strategies. Integrating means to improve food production into cold chain projects, e.g. by also promoting solar water pumps for agricultural uses, can have a direct, positive effect on a project's overall viability. The same could be achieved through identifying suitable uses for excess energy generated during periods of low cooling demand.

6. Summary of Challenges and Recommendations

Cold chains are ***integrated systems***, which can extend across a number of different segments in different food value chains. Shortcomings at any level of a cold chain can jeopardize its viability as a whole. All too often, cold chains in LICs are being targeted selectively by different stakeholders, resulting in more or less isolated actions. To effectively address the cooling needs in food systems and promote social and economic benefits a comprehensive approach is required. Projects should seek to identify potential bottlenecks and consider project impacts beyond individual segments of a value chain, as well as ensuring that a promoted cold chain element is linked to existing cold chains, or suitable target markets for cooled produce. Such a ***comprehensive approach*** requires the involvement of a broad range of key ***stakeholders***.

The operation of cold chains requires specialist knowledge and skills in a number of areas, including general awareness and knowledge of the effects of temperature on food products, product specific storage requirements, good practices in the handling and packaging of food products, skills required for the operation of cooling technologies, as well as business, supply chain management and logistics. Addressing the existing skills gaps in developing countries through extensive ***capacity building and training*** is essential, in order to promote the establishment of well functioning cold chains.

The viability of cold chains is linked closely to the ***production and postharvest handling*** of foods. Optimizing production and postharvest handling of foods to minimize heat intake and increase product quality can reduce the energy needed to cool food and improve overall economic viability. By establishing modern facilities for the sorting and grading of foods, for example, product quality can be increased and the application of cold chains for high quality produce can help to maximise economic benefits. Improvements to production processes can furthermore help to mitigate ***seasonal variations*** in production volumes, increasing the utilization rate of available cold storage space alongside its economic viability.

The availability of a ***reliable and affordable energy supply*** is a key precondition for the development of cold chains in developing countries. Increasing the energy access in rural areas is crucial for addressing existing cold chain deficits during the "first mile", from food production to the transport to markets or processing facilities. Through the promotion of ***decentralized renewable energies*** and ***energy efficiency*** technologies, high operational costs for cold chains in developing countries can be reduced significantly, thus improving their overall economic viability.

Policy and regulation have a key part to play in promoting the widespread establishment of cold chains in developing countries. Policymakers and regulators carry a key responsibility, from the enactment and enforcement of food safety and quality regulations, to the establishment of the necessary transport and energy infrastructure in rural areas, and promoting the market development for cooling technologies. Integrating assessments of existing cold chains and cooling needs into overall ***infrastructural planning*** would aid decision-making processes concerning infrastructural developments. Thus a holistic development strategy can be pursued comprising transportation networks, water and electricity distribution and access points, producer and market locations and numerous other parameters.

The widespread development and operation of cold storage infrastructure requires significant financial investments. In order to facilitate these investments, ***improved access to finance*** for food producers, wholesalers and retailers, tailored specifically to the economic needs and possibilities of potential entrepreneurs, is necessary.

7. Conclusion

Well functioning cold chains have an important part to play in reducing food losses, increasing value creation and improving energy supply in areas which are currently underserved. Promoting cold chains as an investment into food security is highly cost effective in comparison to increased production, while also allowing for economic, social and environmental benefits to be reaped in the process. The concept paper at hand aimed at providing a basis for further discussion on advancing the cold chain coverage in developing countries, by providing an overview on food cold chains for fruit and vegetables, dairy products, fish and meat, identifying existing challenges and possible solutions towards improving cold chain coverage and cold chain management in these countries and strengthening food security.

In order to effectively promote the development and operation of sustainable cold chains in developing countries, the following aspects should be considered:

- Firstly, any intervention should be tailored around identified needs for cooling. If needs are not or only partially known, then preliminary research should be conducted e.g. through value chain analyses.

- Secondly, any intervention should aim at establishing an uninterrupted cold chain, as any disruption can quickly lead to damages and loss of the initial advantages that isolated cooling infrastructures may bring. Only a well integrated cold chain infrastructure, covering the value chain from production to consumption, will significantly reduce food losses.

- Thirdly, quantity and type of food product including seasonal variations must be well matched to the cooling technology and energy supply system used. Only where this is the case, a solution will be able to meet the demand for cooling at the least possible cost.

- Fourthly, efficient development in the sector will depend on the development of sustainable business models for the operation of cold storage facilities. Government support schemes may be useful to make operating a cold chain viable from a business perspective.

- Fifthly, operating cold chains require sound knowledge of technology and business management. Capacity building and training are necessary to determine initial size and specific storage needs of different food products, establish an understanding of temperature management as well as good practices in food handling to ensure that perishable food products last longer and maintain their nutritional benefits to the final consumer.

- Finally, no single cold chain technology or approach can provide a one-size-fits-all solution to the multitude of challenges impeding the widespread access to food cold chains in developing countries. Any intervention hence has to be developed according to local circumstances and needs.

Annex

Annex I Project examples in development co-operation

GIZ supports several projects working on technology demonstration targeting different steps along the cold chain or dealing with supply value chains, including cold chains. This chapter provides a selection of projects in implementation and their lessons learnt, as well as outline concept ideas which are currently being developed.

PROJECT	COUNTRY	FOOD PRODUCT(S) IN FOCUS	COLD CHAIN ELEMENT(S)	ENERGY SUPPLY	PROMOTED APPROACH / TECHNOLOGIES
Conversion of Supermarket Refrigeration Systems from F-Gases to Natural Refrigerants	South Africa	Various	Retail (supermarket)	On-grid	Demonstration and promotion of the complete conversion from F-Gases to natural refrigerants in supermarket cooling facilities
Converting the Production of Refrigeration Equipment to Natural Refrigerants and the Development of PV Solar powered Refrigerators	Swaziland	Various	Various	On-grid	Establishing energy efficient and climate friendly supermarket refrigeration Promoting switch to natural refrigerant Ammonia (R-717) Application of CO_2 cascade
Solar powered cold rooms for fruit and vegetables growers	Nigeria	Fruit and vegetables	Bulk cooling, retail	Off-grid	Development of small-scale solar PV cold storage for local markets Operation of cold storages on a fee for service basis
Piloting ice-production for off-grid fishing communities	Senegal	Fish	Bulk and transport cooling	Off-grid	Finance and support of the technical set-up of the ice machine operated by a women's cooperative
Green Cooling Initiative Technology partnership -energy-efficient and climate-friendly cold room for the fisheries industry	Kenya	Fish	Bulk cooling	Off-grid	Establishing a climate friendly, solar-powered cold room for the fisheries industry at Lake Victoria to enable the de-central collection and aggregated storage of Tilapia fish
Field testing of an innovative solar powered milk cooling solution	Tunisia	Milk	Bulk cooling / transport	Off-grid	Solar PV ice-maker, based on modification of DC refrigerator Application in cooling milk on farm and during transport (milk collection)

PROJECT	COUNTRY	FOOD PRODUCT(S) IN FOCUS	COLD CHAIN ELEMENT(S)	ENERGY SUPPLY	PROMOTED APPROACH / TECHNOLOGIES
Emission mitigation in the transport refrigeration sector through the introduction of innovative logistics and supply structures	South Africa	Various	Transport refrigeration	Off-grid	Climate-friendly development of the transport refrigeration sector in South Africa. Support of the South African government to integrate the transport refrigeration sector into their national mitigation strategy
Off-grid bulk storage of vegetables in rural areas	India	Vegetables	Bilk storage	Off-grid	Provide a holistic approach to help vegetable famers to overcome the main barriers they face in the production, storage, transportation and marketing of horticultural goods
Green Chillers NAMA project	Indonesia	Fish	Retail (fish market)	On-grid	Supporting the Ministry of Fishery procuring an ice flake machine using propane as refrigerant for the auction and selling of fish
Green Chillers NAMA project	Indonesia	Various products	Retail (super-markets)	On-grid	Promotion of cabinet units using propane as refrigerant being 20 %+ more energy-efficient for various supermarkets
Green Chillers NAMA project	Indonesia	Fish	Bulk cooling, fish processing	On-grid	Supporting a fish processing company reinvesting in their ammonia based cold storage and shock frosting

SOUTH AFRICA – CONVERSION OF SUPERMARKETS	
PROJECT	Conversion of Supermarket Refrigeration Systems from F-Gases to Natural Refrigerants
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	Pick n Pay (large supermarket chain in South Africa)
DURATION	October 2000 until September 2012
COSTS	~ 1.750.000 € (Project is funded by the German Federal Ministry for Environment, Nature conservation, building and nuclear safety within the IKI)

Project background

Cooling needs / demand

South Africa is facing a shortage of energy supply while prices for electricity are rising. Supermarkets, which are an important sector of the economy, need large amounts of electricity, of which most is used in their refrigeration and air-conditioning systems. Additionally, South Africa is responsible for nearly half of the CO_2 emissions for the entire continent of Africa, and about 1.6% of global emissions (EDF/IETA 2014:1). The country is therefore looking for possibilities to manage energy demand and decrease GHG emissions.

Cooling infrastructure / technologies – status quo

Before the project started, all supermarket refrigeration systems in Southern Africa operated on fluorinated refrigerants with high ozone depleting and/or global warming potentials. Alternative and environmental friendly technology was completely unknown.

Business model and ownership

Pick 'n' Pay is a leading food retailer in South Africa. With about 700 stores and 2,000,000 m2 retail space (2012), it holds 30% of the total market share. Therefore, it was determined to be the most committed and relevant for the project. Within the project, two stores (Strand and Randpark Ridge) were chosen to install a pilot refrigeration system using only natural refrigerants. Previously, the both selected supermarkets had very high leakage rates of the refrigerant (up to 80%) due to their high refrigerant charge and the piping installed in walls and floors.

Project component aim and approach

Aim

The project components aimed to demonstrate and promote the complete conversion from F-Gases to natural refrigerants in supermarket cooling facilities. The installation of the two pilot refrigeration systems should led to a wide acceptance and further replication of the new technology in South Africa and other African countries.

Activities to date

In the beginning, field visits to find best technical solution and suitable natural refrigerant were conducted and the necessary data collected. Afterwards local engineering firms were commissioned for the project and the refrigeration systems were engineered and manufactured locally. Installation started in 2009 and a corresponding training for technicians on the safe handling of Ammonia and CO_2 was also carried out. By spring 2010, the new systems were fully operational. It was ensured that the systems would meet European standards EN 378 through safety and quality checks by the German TÜV. Capacities were built through the training of local technicians. The trainings ensured proper maintenance as wells as further replication and development of these new technologies. In addition, an extensive energy management system was also developed in the course of the project, which allowed Pick 'n' Pay to monitor their energy consumption and make corresponding adjustments where needed. GIZ and Pick n Pay promoted the new technology on various information sessions and public events to create awareness for the topic and foster replication.

Promoted business model and ownership

The project was built on the existing cooling infrastructure already provided by the national supermarket chain Pick n Pay. Pick n pay financially and technically assisted to convert the refrigeration and air-conditioning systems in two supermarket stores (Johannesburg and Cape town).

Promoted technologies and energy supply

The new refrigeration system runs with Ammonia (R-717) in the compressors and uses a heat transfer medium for the distribution into the cold rooms and cabinets in the trading area. A CO_2 cascade provides the temperatures needed for the freezer cabinets.

Lessons learned

Monitoring results so far confirm that in the two supermarkets energy savings of 19-26% are achieved. Generally, the implementation of natural refrigerants could safe 1000-2000 t CO_2 emissions annually. Maintenance costs for natural refrigerant systems and conventional systems are comparable while some savings of up to 4000 to 5500 ZAR (South African Rand) annually per natural refrigerant system could be achieved due to lower cost for refrigerant refill. Through the project the first indirect cooling system in a supermarket in South Africa was implemented. Presently, quite a few new supermarkets like the company Makro S.A. are choosing to apply indirect systems using CO_2 in a cascade for low temperature. Pick n pay itself will introduce cooling systems relying on natural refrigerants in 25 other supermarkets and aims to convert all of its supermarkets until 2015.

The achievement of the project objectives strongly depended on the engagement of the supermarket chain. Through a close cooperation with Pick n Pay technology acceptance and positive impact increased and led to a wider spreading of the applied technology.

Sources

- EDF, CDCD, IETA (2015): South Africa: An emissions trading case study. Available at: *https://www.edf.org/sites/default/files/south-africa-case-study-may2015.pdf.*

SWAZILAND – CONVERSION OF SUPERMARKETS	
PROJECT	Converting the Production of Refrigeration Equipment to Natural Refrigerants and the Development of PV Solar powered Refrigerators in Swaziland
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	The Fridge Factory (Palfridge)
DURATION	October 2008 until December 2016
COSTS	2.000.000 € (Project is funded by the German Federal Ministry for Environment, Nature conservation, building and nuclear safety within the IKI)

Project background

Cooling needs / demand

Almost 80% of Swaziland's population still lives in rural areas with a lack of available infrastructure (WHO 2013: Basic statistics). While Swaziland's economy and food supply strongly rely on national agricultural production, the food production has declined in the last year due to factors like droughts and inappropriate agricultural technology (AHO 2015: Food safety and nutrition). Furthermore the populations suffers from the widespread impacts of HIV. To improve the national health situation, the development of health standards is critical for Swaziland.

A functioning cold chain is very important in Swaziland to preserve food and also for the medical supply. This is most critical in rural off-grid areas. Here, solar powered refrigerators can be of great support.

Cooling infrastructure / technologies

Refrigeration equipment in Swaziland used to contain fluorinated refrigerants HCFC R22 (Ozone Depleting Substance) and R134a (HFC) with a high Global Warming Potential.

The project supported the local Swazi manufacturer, Palfridge, to produce refrigerators with climate friendly hydrocarbon refrigerants. These refrigerators have superior energy efficiencies. Additionally a special series of appliances was designed and developed for solar powered off-grid usage.

Business model and ownership

The Fridge Factory situated in Matsapha, the largest industrialised area of the country, produces refrigeration appliances since 2001. The daily output of approximately 500 units for domestic and commercial use, is mainly exported to southern African countries.

Project component aim and approach

Objective

The project supported the conversion of the the production line for domestic and commercial refrigeration appliances of the manufacturer Palfridge to natural refrigerants. With the successful conversion, Palfridge could impressively demonstrate that the environmental-friendly technology can be handled safely also in a developing country.

Activities which have been additionally implemented:

- State-of-the-art safety devices.
- Intensive trainings and appropriate education of the entire production staff.
- Assistance on the design of refrigerators with hydrocarbons with advanced safety features.
- New testing area for quality and safety controls for every appliance.
- Development of information and training material for marketing and service technicians.
- Development of PV solar powered refrigerators which are battery free and store the solar energy through a thermal ice storage.

Promoted business model and ownership

With support of the GIZ, The Fridge Factory became an exemplary manufacturer and pioneer for the production of climate friendly energy efficient refrigerators in Africa.

More environmentally friendly refrigerators are now produced locally and can be sold at reasonable prices. The conversion now enables the company to produce appliance with no ODP and a low GWP impact.

Promoted technologies and energy supply

The domestic and commercial refrigeration appliances produced at The Fridge Factory, now use the natural refrigerants R290 (propane) and R600a (iso-butane) for cooling. These hydrocarbons are highly suitable refrigerants for stand-alone refrigeration equipment in hot climates and increasingly becoming the refrigerant for choice for domestic refrigerators globally. The jointly developed solar cooling technologies for refrigerators can store the energy without battery support and can work completely autonomous in the solar belt regions of the world.

Lessons learned

Results so far prove that the conversion of the annual production (approx. 60,000 units) cuts direct emissions of F-gases by up to 14,800 tonnes CO_2e per year. Furthermore, the units are more energy-efficient and save more than 20% less energy consumption compared to conventional ones. The solar powered units can produce the required cold completely fossil fuel free and store the energy battery free. These savings will not only reduce CO_2 emissions but also cut electricity costs for households and commercial end-users. The implementation of modern production technologies also has a positive effect on Palfridge's market position strengthening a local African company against global competition and maintains around 700 jobs. Other refrigerator manufactures especially from South Africa have followed the examples of Palfridge and also converted to HFC free technologies.

Sources

- WHO (2015): Swaziland: WHO statistical profile. Available at: *http://www.who.int/gho/countries/swz.pdf?ua=1.*

- AHO (2015): Food safety and nutrition. Available at: *http://www.aho.afro.who.int/profiles_information/index.php/Swaziland:Food_safety_and_nutrition.*

NIGERIA – COLD STORAGE FOR FRUIT AND VEGETABLES	
PROJECT	Solar power cold rooms for Fruits and Vegetables Growers in Nigeria
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	Institute for Air Handling and Refrigeration Dresden (ILK Dresden) Smallholders Foundation (local NGO)
DURATION	10/2015 – 12/2016
COSTS	80.000 EUR

Project background

Cooling needs / demand

Due to high ambient temperatures and humidity, decay processes of fruits and vegetables in Nigeria are accelerated. These post-harvest losses do affect over 70 million Nigerian farmers, agro processors and other actors along the food supply chain. Moreover, post-harvest food losses restrict opportunities of market access and income improvements substantially. An average of 5% of vegetables and 35% of fruits is lost after harvest. This leads to an estimated income loss of 25% (Rockefeller Foundation Food Waste and Spoilage Initiative 2014). Besides food losses, production inputs (i.e. fertilizer, water, pesticides) are wasted. This unnecessarily inflates the environmental load of farming in Nigeria and could lead to decreased soil quality, biodiversity loss, and drought/desertification.

Cooling infrastructure / technologies – status quo

Mostly no cooling facilities are available at local wet markets. Furthermore, there is a lack of suitable refrigeration appliances. Available cold rooms often run with diesel motors causing GHG emissions and unaffordable high operation costs. Moreover, climate harmful refrigerants which have a high GWP are used. Especially in rural areas there is no access to proper storage facilities and reliable electricity supply.

Business model and ownership

Usually, food production in Nigeria is done by small-scale and family owned businesses. Especially women are often responsible for farming and selling of environmental products. They are therefore disproportionally affected by port-harvest losses and the economic consequences.

Project component aim and approach

Aim

The project aims to enable Nigerian farmers to cool their harvested fruits in an energy-efficient and climate-friendly solar powered cold room. It will set up refrigerated storage facilities which are environmentally sound (energy efficient and in combination with natural refrigerants), cost efficient (affordable for farmers) and socially beneficial (through reducing income losses). Through the use of natural refrigerants and renewable energy preventing GHG emissions the project will contribute to climate protection. Furthermore it will lead to women empowerment and enhanced food security.

Activities to date

The project activities will include:

- Trainings by ILK for Smallholders foundation on how to build operate and maintain the solar-powered cold store. Training concept is already completed and available.
- One pilot solar powered cold room will be installed.
- Afterwards, two additional solar-powered cold rooms are assembled in Nigeria, installed and tested in two different regions in Nigeria.
- Monitoring results of the solar-powered cold store's operation.
- Development of an upscaling strategy.
- Promoted business model and ownership.
- Smallholders foundation has long experiences working in the Nigerian agricultural sector and with small scale farmers.
- Farmers storing their products in the cold room will have to pay a certain amount to Smallholders foundation to make the project financially independent in long term.
- ILK Dresden will provide technology expertise.

Promoted technologies and energy supply

The project will provide a cold storage which operates off-grid with photo voltaic and a natural refrigerant (R-290 – propane with a GWP of 3). The unit consists of the cold room with internal ice storage, a refrigeration unit, a secondary fluid circuit, battery power electronics, a PV generator and a shading roof. In case of deficient sunshine a small back up battery is sufficient to ensure energy supply. The average temperature will be from 5°C to 7°C. 200 kg of new fruits could be easily cooled down on daily basis.

Risks and challenges

- No proper usage of the cold room due to mismanaged food harvesting and food cooling chain.
- Availability of components and square parts (technology is newly introduced to Nigeria), but ILK Dresden will provide all needed equipment on long-term basis.
- Adequate servicing of installation (keeping in mind the flammability of R-290 refrigerant). ILK Dresden will conduct the training of Nigerian personnel in Germany.
- Cost-efficiency.
- Water supply.

Lessons learned

Project is still in stage of planning.

Sources

- *http://faostat.fao.org/CountryProfiles/Country_Profile/Direct.aspx?lang=en&area=159*
- *http://databank.worldbank.org/data/reports.aspx?source=2&country=NGA&series=&period*

SENEGAL – ICE-PRODUCTION FOR FISH COOLING	
PROJECT	Piloting ice-production for off-grid fishing communities
RESPONSIBLE PROJECT AT GIZ	PERACOD
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	Ziegra Messtronic SEV (Soleil-Eau-Vie) OMEGA Technologie
DURATION	December 2014 – December 2016

Project background

Cooling needs / demand

Félane is a small community in the Fatick region of southern Senegal. The majority of the 1000 inhabitants makes a living from fishing and related activities. While some of the catch is consumed or traded locally, a substantial share is sold to markets further away. The closest collection point for Félane is Foundiougne, at a distance of 35 km. The transportation to the Foundiougne is organized by traders who normally use horse drawn carriages with a transportation time of 3 hours.

Fishers in Félane – and similar, small remote fishing villages – arrive at night at their harbors. The next morning the catch needs to be delivered to Foundiougne where wholesalers from Dakar will pick it up for further transportation and selling. Under the given climatic conditions, fish and marine products deteriorate at a high rate which reduces both the lifespan of the product and the ability for fishermen to obtain good prices for their catch. Therefore, the catch needs to be consequently cooled during its nightly storage in Felané and transportation to the local market in Foundiougne.

Cooling infrastructure / technologies – status quo

The fish wholesaler bring ice produced in Dakar to Foundiougne using it exclusively for their own transportation. Only one on-grid ice factory is available in Foundiougne to meet the cooling demands of the local markets. However, the transportation and storage of ice does not work properly and the ice never arrives at the places where it is actually needed. Consequently, the factory sells very little amounts of ice.

Business model and ownership

A Women's co-operative operates the ice production machine. In the piloting phase, ice was sold in 20 Liter buckets (~ 10 kg) to Félane fishers for 1000 FCFA (1,5 €) each. This amounts to ~150 €/t. The key customers are fishermen originating from Félane, but fishers from other villages close-by may also buy ice produced by the co-operative.

Project component aim and approach

Aim

The PERACOD project finances and supports the technical set-up of the ice machine. A side outcome of the pilot project is the development of a package solution for ice making as a standalone application, with PV electricity generation supplying ice machine, water pump and control units.

Activities to date

Activities include:

- Construction of an ice production hall by the women's co-operative.
- Installation of one system with water supply, electricity supply and ice production machine, design capacity 375 kg/24h ice and 13 m² water/24h.
- Business development service / training.
- Trainings regarding ecological agriculture.
- Monitoring technological and operational performance under field conditions, with the help of state-of-the art monitoring equipment.
- Analysis of business case and future strategies for scaling up the technology use at other sites.

Promoted business model and ownership

After the pilot phase it is envisaged that co-operatives at sites with a high demand for ice will set up the standalone solution for ice production. Investment and operating costs are to be covered by the sale of ice. Ownership is with the co-operative.

Promoted technologies and energy supply

The ice production machine is a Ziegra ZBE 350 with a design production of 350 kg/day. For water supply, a 200 W Lorentz pump was installed that pumps water

from 15 meter depth into a 15 m³ tank. The entire set-up is powered by a 7 kWp PV installation. Additionally, eight batteries of 12 Volt (200 Ah) are installed.

Lessons learned

Due to the very high ambient temperatures in Senegal a modification to the standard design had to be applied. Water pumped from the well passing through the tubes was heating up more than expected. A customised pre-cooler had to be installed to reduce the temperature of water at intake of the ice production machine.

However, the local agriculture can benefit from water excess and resulting electricity surplus can be used by activities like charging phones and money transfer. Hence, additional income can be achieved and the feasibility of the ice machine increases.

Furthermore, the set up of the ice machine has created three jobs. Two women and a young man from Félane who sell ice on daily basis and earn up to 3000 FCFA each day.

KENYA – SOLAR POWERED COLD STORAGE FOR FISH	
PROJECT	Green Cooling Initiative Technology partnership -energy-efficient and climate-friendly cold room for the fisheries industry in Kenya
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	Tbc
DURATION	October 2015 until December 2016
COSTS	Estimated around 50.000 €

Project background

Cooling needs / demand

Kenya's fishery sector contributes with 5% to the country's GDP and supports the livelihood of over 500,000 people direct or indirectly (FAO 2014:72). Lake Victoria is Kenya's dominant source of fish with over 92 percent (FAO 2007:2) of freshwater fish production. Although freshwater aquaculture is not widely adopted yet it has a large potential in Kenya and could contribute significantly to wealth creation, employment and food security (FAO 2007:8). Fish is an invaluable source of protein food to many Kenyans, especially those living in the vicinity of the major fisheries and towns.

Kenya is affected by a strong population growth linked with a rapid urbanization which results in an urgent need for the development of fish farming to secure food supply. Furthermore as a country with high ambient temperatures the demands for cooling are rising and the RAC sector could contribute strongly to the country's GHG emissions. RAC related emissions in Kenya are predicted to grow 4 times from 2010 to 2030 under a business as usual scenario (GCI 2015:Country data). Therefore, climate friendly cooling technology must be further implemented and promoted to reduce Kenya's GWP and ensure the preservation of fish endangered by climate change.

Cooling infrastructure / technologies – status quo

The physical infrastructure in Kenya is relatively poor; there are especially poor access roads to landing sites and a lack of electricity. These circumstances impede fish industry development and proper food storage.

Business model and ownership

Fish farming at Lake Victoria is dominated by small scale and artisanal fishers. Consequently, the amount of fish produced by individual fishers is relatively small and cool trucks from larger cities (i.e. Nairobi) do not collect fish at the individual fishing sites. Instead local fishers carry the fish with motorbike/car/trucks to a consumption point where local buyers come to select which fish they will buy. The remainder is used for own consumption or discarded.

Project component aim and approach

Aim

The project aims to provide a climate friendly cold room for the fisheries industry at Lake Victoria. The cold store should serve the purpose to enable the de-central collection and aggregated storage of Tilapia fish on ice chips in boxes before it is transported to larger markets in Nairobi. The cold room will consist of a locally produced cold room body manufactured according to state-of-the art insulation standards, highly energy-efficient ice making and refrigeration machines using R-290 (propane) as refrigerant and a photovoltaic power system to provide electricity during day time.

Thereby, the cold room means an important step in creating an efficient cold chain for local fresh fish supply and demand.

Activities to date

Development of technical concept and consultation with Kenyan stakeholders (fish farmers and traders, Ministry of Environment, Investors).

Identification and selection of potential co-investing operators

Promoted business model and ownership

The Green Cooling Initiative project that is implemented by GIZ provides the technical concept for the cold room. In addition, local cold room body builders are trained on how to manufacture cold room panels with climate and ozone friendly insulation materials. The refrigeration equipment is supplied by European producers whereas the PV system is provided by local suppliers.

The co-investing operator brings in the fish harvest and treatment infrastructure and staff and provides the land near Lake Victoria.

Given sufficient scale of fish supply and demand according to the calculated dimensions of the cold room, return on investment perspective is proven attractive.

Promoted technologies and energy supply

The project relies on a cold room with R290 (Propane) as a climate-friendly refrigerant and a PV solar power system placed on the rooftop. The constant average temperature of the cold room should be 2°C with a 90 percent humidity level. The cold room will be insulated with EPS (Expanded polystyrene), XPS (Extruded polystyrene) foam or PU (Polyurethane) all being climate and ozone friendly foam blowing agents, and according to state-of-the-art insulation standards. A refrigeration unit will be placed on the back side of the room. Inside fish will be stored in Euro sized plastic boxes covered with ice chips. The cold room holds a storage capacity of up to 5 tons per week. If stored properly fish could be preserved for up to 10 days. Processes in the cold room include weighing of the fish, processing, cleaning and storage.

Lessons learned

Project is still in stage of planning.

Sources

- FAO (2014): Food Loss Assessments: Causes and Solutions Case Studies in Small-scale Agriculture and Fisheries Subsectors. Available at: *http://www.fao.org/fileadmin/user_upload/save-food/PDF/Kenya_Food_Loss _Studies.pdf.*

- FAO (2007): Country profile Kenya fisheries. Available at: *ftp://ftp.fao.org/FI/DOCUMENT/fcp/en/FI_CP_KE.pdf*

TUNISIA – MILK COOLING	
PROJECT	Field testing of an innovative solar powered milk cooling solution (Tunisia)
RESPONSIBLE PROJECT AT GIZ	Powering Agriculture
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	International Center for Agricultural Research in Dry Areas (ICARDA), University of Hohenheim, Phaesun, and National Agricultural Research Institute of Tunisia (INRAT)
DURATION	February 2016 – December 2017

Project background

Cooling needs / demand

The region of Sidi Bouzid, in central Tunisia, is responsible for approximately one sixth of the national milk production in Tunisia. The majority of its milk is produced by small and medium sized dairy farms with less than ten cows and a daily milk output below 200l. Their milk is currently being produced on farm and transported to milk collection facilities without any form of cooling. In this situation, bacterial growth during on farm short-term storage and transportation represents a significant problem for the dairy sector.

Under the given climatic conditions, milk can exceed the maximum bacterial count prescribed by Tunisian food safety laws after about two to five hours. During the hottest periods of the year, lack of quality is the most common reason for the refusal of milk at collection centers. Furthermore, due to low production volumes, evening milk collection is not available year round, thus causing additional on-farm losses.

Cooling infrastructure / technologies – status quo

During the 'first mile' of the dairy value chain, from on-farm production until the transportation to collection centers, no form of cooling is currently being applied.

Business model and ownership

Milk is predominantly produced by small and medium sized dairy farms and delivered to middlemen, who mix the milk of several farms in their own milk cans and transport them to collection centers. At the collection centers, milk quality is being assessed and the amount of suitable milk is documented. Farmers and transport entrepreneurs are paid weekly, based on a centralized price-system through a farmer´s cooperative.

Project component aim and approach

Aim

The project supports the field assessment of a solar-powered milk cooling solution, designed to meet the refrigeration needs of small and medium-sized dairy farmers in developing countries, in Sidi Bouzid, Tunisia. The ice-based cooling solution was developed specifically to overcome the challenges during short-term on-farm storage of milk and transportation to collection centers.

Activities to date

Planned activities include:

- Installing 10 small-scale milk cooling systems, with a capacity of 60l per day each, at 6 dairy farms with production volumes ranging from 60l to 180l per day.

- Monitoring technological performance under field conditions, specifically by measuring achieved milk quality improvements.

- Analyzing the business case and future strategies, such as quality-price-premiums, to systematically promote improvements in milk quality and productivity of the regional dairy industry.

- Assessing social acceptance and social impact.

Promoted business model and ownership

As of now, it is envisaged that milk coolers are owned by dairy producers and installed on farm. Farmers recoup the necessary investment through an increase in their milk production (improved storage of evening milk, decrease of rejected milk) and achieving a price premium for their produce due to on-farm cooling (price premiums exist already) and better quality (not yet applied in the region).

However, the field trial aims to assess the viability of the proposed business and ownership model and, if necessary, provide recommendations for future adjustment.

Promoted technologies and energy supply

The milk cooling solution developed by the University of Hohenheim is based on the commercially available Steca PF 166 DC refrigerator, with a modified control unit. The modifications allow the refrigerator to function as a smart solar freezer, by adjusting its operation to the availability of solar energy. The freezer has a volume of 166l and is capable of producing approx. 8-13 kg of ice per day. The system comes with 25 reusable ice tins of 2l capacity and two 30l isolated milk cans with removable ice compartment. To cool down 30l of milk from 36°C to 15°C in one of the supplied milk cans, the systems needs 6kg of ice and approx. one hour.

The smart solar freezer is powered by 600Wp solar PV modules. Due to the application of a 120 Ah battery and thermal energy storage (PCM - ice), the system is able to run autonomously for up to 7 days during periods of low solar radiation and high ambient temperatures.

Lessons learned

The project is currently shipping 10 systems to the final site, with the actual field assessment due to start in April 2016.

SOUTH AFRICA – TRANSPORT REFRIGERATION	
PROJECT	Emission mitigation in the transport refrigeration sector through the introduction of innovative logistics and supply structures in South Africa
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	Department of Trade and Industry (DTI) South African Bureau of Standards (SABS) Transfrig (domestic manufacturer of transport refrigeration equipment)
DURATION	June 2012 until November 2016
COSTS	~ 3.480.000 € (Project is funded by the German Federal Ministry for Environment, Nature conservation, building and nuclear safety within the IKI)

Project background

Cooling needs / demand

South Africa's economy depends largely on agriculture and trade (retail) – two sectors in which transport plays a vital role. The transport and distribution of refrigerated goods is an important part of the greenhouse gas emission balance of cold chains. It is estimated that under a business-as-usual scenario, emissions in the transport refrigeration sector will increase from the current two million tons of CO_2eq*, to above five million tons $CO2_2$q by 2020 in South Africa.

Cooling infrastructure / technologies – status quo

There are about 14 000 trucks and trailers in the refrigerated transport sector in South Africa. In terms of their direct greenhouse gas emissions, each cooling unit of the truck contains refrigerants, mainly the hydrofluorocarbon blend R404a, which has a global-warming potential (GWP) of 3 922 and to a lesser extent the ydrofluorocarbon 134a (HFC-134a), which has a GWP of 1 430 times that of CO_2. Furthermore, the refrigeration unit and truck engine consume fuel and therefore create indirect emissions in the form of CO_2. These indirect emissions contribute less than 50% in smaller trucks, but up to 75% in trailers.

Project component aim and approach

Aim

The project aims to contribute to the climate-friendly development of the transport refrigeration sector in South Africa through two main interventions: changing to natural refrigerants, such as hydrocarbons, with less global warming potential, and reducing the energy consumption of the cooling and transportation process through energy efficiency improvements. The project further supports the South African government to integrate the transport refrigeration sector into their national mitigation strategy.

Activities to date

Analysis of the sector and recommendations of pilot measures

Establishment of a steering committee with members from South African Government Departments, associations and industry representatives

Establishment of a thermal test chamber to verify the the insulation capacity of refrigerated bodies. The test chamber is being installed in the framework of a Public Private Partnership (PPP) between the Department of Trade and Industry (dti), the South African Bureau of Standards (SABS) and GIZ.

In line with the activities related to the test chamber, a national standard for the testing of the insulation capacity of refrigerated vehicles is being drafted by a specifically established sub-committee at the SABS Standards Division, responsible for standard developments. The standard will be accompanied by a certification and an auditing scheme.

To ensure energy efficiency improvements and enable South African manufacturers of refrigerated trucks and trailers to meet the requirements of the future standard, the project offers training on design and manufacturing processes.

In terms of refrigerants in use, a prototype working with a low-GWP hydrocarbon refrigerant (Propane, R290) is being developed in cooperation with Transfrig, a local manufacturer of refrigeration systems..The system has been designed and assembled and currently a safety concept is being elaborated to ensure a smooth field trial in 2016.

Various training courses on transport refrigeration technologies and safe handling of natural refrigerants have been held. An additional training on cold chain logistics to optimize operational procedures is being envisaged for 2016.

The dti is considering an accession of the United Nations treaty "Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage (ATP)".

Lessons learned

Project is not completed yet.

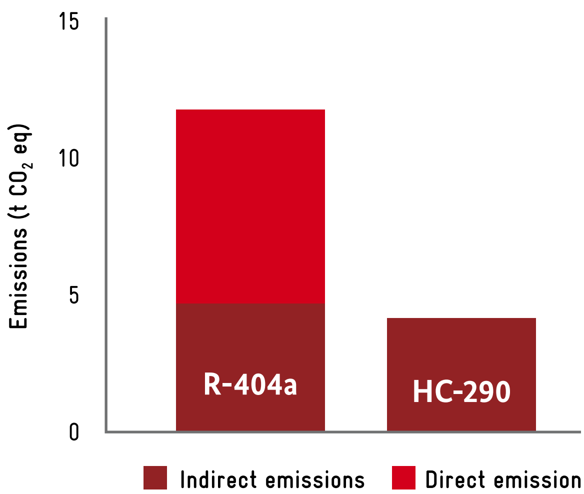
The body building quality in South Africa is very poor with little to no consistency in terms of manufacturing quality. Estimated emission reductions due to improved insulation are around 15 t CO_2 per year per trailer and around 10 t CO_2 per year per truck (see assumptions below).

Trailer, long-distance, -20°C	k-value = 1.2	k-value = 1.2
Fuel usage (L/h)	2.3	1.1
Running time per (h/year)	4,800	4,800
Annual fuel usage (L)	10,900	5,100
Annual fuel costs (ZAR) at 13 ZAR/L	142,000	66,500
CO_2 emissions (t/year)	29	14

Truck, distribution, -20°C	k-value = 0.9	k-value = 0.4
Fuel usage (L/h)	1.7	1.0
Running time per (h/year)	4,800	4,800
Annual fuel usage (L)	8,200	4,700
Annual fuel costs (ZAR) at 13 ZAR/L	106,000	60,500
CO_2 emissions (t/year)	22	11

Through the use of R290, compared to R404A, the COP can be increased by up to 27% at -20°C and up to 28% at 0°C. The refrigeration charge can be reduced significantly from 3,5 kg to 0,65 kg and total emissions are reduced from 11,8 t CO_2-eq to 4,0 t CO_2-eq.

	R-404a unite	HC-290 unite
GWP	3,922	3
Charge size	3.5 kg	0.65 kg
Annual leakge rate	50 %	50%
Direct emissions	6.9 t CO_2 eq	0.001 t CO_2 eq
Fuel consumption*	1.2 L/h	1.0 L/h
Runtime hours	1,500 h/year	1,500 h/year
Indirect emissions	4.8 t CO_2 eq	4.0 t CO_2 eq
Total emissions	11.8 t CO_2 eq	4.0 t CO_2 eq



INDIA – BULK STORAGE FOR VEGETABLES	
PROJECT	Off-grid bulk storage of vegetables in rural India
RESPONSIBLE PROJECT AT GIZ	IGEN RE (Indo- German Energy Programme – Renewable Energy component)
PARTNERS / IMPLEMENTING ORGANIZATIONS (COOLING COMPONENT)	SwitchON
DURATION	June 2014 to February 2015

Project background

Cooling needs / demand

In India, food losses of fruit and vegetables across the entire value chain from producers to consumers currently amount to about 40% of the production. A key driver for these high food losses is the lack of appropriate cold chain infrastructure. As of now, cold storage is only available for approximately 10% of India's perishable produce.

The situation is most severe in rural areas, where key infrastructure is widely lacking. A reliable supply of electricity is unavailable throughout large parts of rural India. The transport infrastructure in rural areas is currently underdeveloped and farmers lack the means to transport their produce to suitable target markets.

Often, small-scale producers are highly dependent upon middlemen (Aratdars), brokers, and wholesalers for selling their produce. Horticultural value chains in rural India typically contain as much as 5-7 intermediaries. It is in part due to this heavy involvement of middlemen that prices paid by consumers may in some locations be up to 400% higher than the amount producers receive for their goods.

Cooling infrastructure / technologies – status quo

In rural areas, there typically is very little or no cold chain infrastructure in place. Some cooling facilities may be available at the later stages of the value chain, e.g. wholesale or retail. Existing cold storage facilities are situated mostly in close proximity to urban centers. Cold storages are only available for approximately 10% of India's perishable produce. Where cold chain infrastructure is in place, it is often designed solely for the storage of potatoes.

Project component aim and approach

Aim

The project aimed at providing a holistic approach to help vegetable famers in the Nadia district of West Bengal to overcome the main barriers they face in the production, storage, transportation and marketing of horticultural goods. The approach sets out to link the establishment of cold storage facilities with improvements in production and post-production handling of vegetables, towards the backend of the value chain, and to an improved approach for the transport and marketing of goods, towards the front-end of the value chain.

By implementing these improvements along the vegetable value chain, the project aims to increase farmers' income by 10-20%.

Activities undertaken to date:

- Established a farmer producer organization (FPO) to take over functions previously provided by middlemen.
- Established collection centre and cold storage facilities for agricultural produce.
- Organized transport from farms to collection center and on to markets, using two collection vans.
- Trained farmers in the use of cooling technology and modern agricultural practices (including organic farming), and provision of marketing support for FPO.
- Installed facilities aggregate approx. 2000 kg of horticultural produce per day, from a pool of over 1000 farmers; so far, over 400 MT of agricultural produce have been processed.

Promoted business model and ownership

The project organized small-scale vegetable producers in the area in one Farmer Producer Organization (FPO), which now provides a number of services to local farmers. Vegetables are collected at farm gate from producers within a 50 mile radius. Upon arrival at the collection centre, the FPO is responsible for cleaning, grading, packing, and storing the collected produce.

The newly constructed solar-powered cold storage is used mainly to store FPO produce, while excess cold storage capacity is rented out to producers not associated with the FPO. The main expected benefits of the cold storage are an increase in the amount of produce for sale, through reduction of postharvest losses, and a greater flexibility for farmers in when to sell their produce, allowing them to avoid selling during low price periods.

The FPO further provides a linkage to suitable wholesaler and consumer markets and organizes the transport of horticultural produce to these markets.

Promoted technologies and energy supply

The installed 9MT solar-grid-hybrid cold storage uses the CoolBot technology to control a conventional air conditioning unit. By modifying key operational parameters of the AC, the CoolBot creates a temperature controlled environment suitable for chilling fruits and vegetables. The applied solution is significantly less expensive than comparable vapour compression refrigeration systems.

With regards to power supply, the installation uses 3.4 kWp solar PV for power generation during the day, while relying on grid electricity at night. Power availability is further increased through the installation of a 75 Ah battery.

Lessons learned

Organizing small-scale producers, e.g. by creating an FPO, is a key precondition for a functional rural cold chain. Otherwise, the required knowledge and management functions are simply too complex and cumbersome.

“Cutting out the middlemen” can be one way to improve the situation for small-scale food producers in India. By providing direct linkages to markets, producer prices may be increased substantially in some instances.

Agricultural produce should be graded and sorted before being introduced into the cold chain. To maximize economic benefits, cold storage should be used for high quality (grade A or B) produce only.

Using cold storage to capitalize on short-term price fluctuations has proven largely infeasible, as farmers are under significant cash flow constraints and depend on selling their produce as quickly as possible.

Suitable Transportation remains a key bottleneck. The use of unrefrigerated vans leaves produce susceptible to deterioration during the several hours, 150 km transport to markets. Reefer vehicles, on the other hand, remain unaffordable.

Annex II Stakeholders

Developing countries often have only limited access to green technologies and may lack capacity to operate them safely and most efficiently. When handling and selling perishable foodstuff speed is often a key issue in regard to a cold chain. Measures that help to improve management along the cold chain are, for example, well-planned and operated logistics, regular services and maintenance, setting up a coherent infrastructure, training of key players, including refining their management skills, and creation of sustainable markets for the design, use and funding of cold chains. However, capacity building and training need to differ by target group. It is often difficult to reach the respective stakeholders and to link them up within the necessary structures. It is worthwhile to develop and tailored approaches directly targeting the various groups of actors along the cold chain. The following table gives a brief overview over the most important players, their field of interventions and possible measures to support them.

TYPE	FIELD OF ACTIVITY	SUPPORT
Smallholder farmer/ cooperatives	Post-harvest cooling	Trainings on cooling methods, produce specific storage and handling requirements and economic benefits (behaviour change), technical and financial support in form of selection and installation of suitable storage spaces; awareness raising
Transport/logistic companies	Transport refrigeration	Mainly technical support and technical training; technology transfer/cooperation
Traders/middlemen/ distributers	Temperature management during handling and transport	Trainings for technicians on refrigeration technologies and monitoring; capacity development of decision makers within trade companies on technology choices, economic benefits, energy efficiency and environmental awareness
Processors/packaging	Temperature management during food processing and/or packaging and storage	Trainings for technicians on refrigeration technologies and monitoring; capacity development of decision makers within the companies on technology and packaging choices, economic benefits, energy efficiency and environmental?
Supermarkets/ retailer	Temperature management during display	Trainings for technicians on commercial refrigeration technologies and monitoring; capacity development of decision makers within retail companies/supermarkets on technology choices, economic benefits, energy efficiency and environmental awareness/"green branding"
End-consumer	Consumption	Awareness raising/marketing campaigns on sustainable consumption, including, waste, energy efficiency and environmental/climate benefits

Other stakeholders that need to be addressed within the entire process are actors on local and national policy level (e.g. policy makers in the agriculture, energy, education, health and nutrition sectors), as well as stakeholders from research, NGOs or potential financing institutions. Access to refrigeration technologies is one major barrier for the introduction and dissemination of sustainable cold chains. It is obligatory to address and involve the private sector, including manufacturers, suppliers and servicing companies to provide equipment and know-how along the cold chain.

Annex III Cooling Technologies: Selected examples

Vapour compression refrigeration

Product overview:

	TYPE / DESIGN	STORAGE SIZE / VOLUME	TEMPERATURE RANGE	ENERGY REQUIREMENTS AND STORAGE	APPROXIMATE COSTS	REFRIGERANT
CoolBot	Walk-in cold room / refrigerated trailer	Variable – larger installations (approx. 60m³ and above) require multiple CoolBots	2°C and above	110V AC	$150 US to $299 US for CoolBot unit	Various
DanSolar Cold Storage Container	Walk-in cold room	68m3 (68,000l)	-10 to 10°C	Not specified	Approx. $39,500 US	Not specified
Promethean Cold Storage System	Walk-in cold room	18m3 (18,000l)	4.0 to 4.5°C	220V AC Thermal battery maintains temp. for up to 20h per 4h charge cycle	Not specified	Halogenated (R-404a)
Promethean Conventional Milk Chiller	Milk chiller	1,000l	4 to 4.5°C	220V AC Thermal battery chills up to 500l of milk per 4-5h charge cycle	Not specified	Halogenated (R-404a)
SolarChill	Chest-type cooler	50l/100l	2 to 8°C	12/24V DC Ice battery maintains temp. for up to 3-5 days per charge cycle	Approx. $1,800 US to $2,800 US for 50l vaccine cooler model	Natural
Steca PF 166/PF 240	Chest type refrigerator	166l/240l	2 to 12°C (refrigerator) -20 to -10°C (freezer)	12/24V DC	900€ (PF 166) / 1,440€ (PF 240)	Halogenated (R134a)
SunDanzer commercial refrigeration containers	Walk-in cold room	10', 20' and 40' models, approx. 16m³- 68 m³ (16,000- 68,000l)	Not specified	220V AC	Not specified	Halogenated (R-134a)
USDA PortaCooler (mechanical refrigeration design)	Refrigerated trailer	3.5 to 7.0 m³, (3,500-7,000l)	2°C and above (when used with CoolBot)	110V AC or diesel generator (2kW)	Build your own – Material costs approx. $1,500 US (incl. CoolBot); cheaper with used air conditioning unit	Various

CoolBot, a special vapour compression control application:

- Cooling unit consisting of standard air conditioning and small CoolBot controller.
- Applicability: Applicable across non-freezing temperature range; less moisture loss than conventional vapour compression; primarily cold storage.
- Energy use: Estimated to be about 25% more efficient than conventional units.
- Costs: According to some sources costs reduced by up to 90% compared to conventional vapour compression system, but likely to be less in reality; about $4,300 US for 6 ton, 20m2 cold room (not including required generation capacity), cost of CoolBot technology represents very small fraction of total cost ($150 US to $299 US); overall cost can be reduced considerably by using a used air conditioning unit.

DanSolar Cold Storage Container

- Standalone solar PV refrigeration solution designed for off-grid application.
- Storage container fur bulk storage of produce with an overall volume of $68m^3$.
- Temperature range from -10 to 10°C, suitable for most food products.

Promethean Cold Storage System (CCS) and Promethean Conventional Milk Chiller (CMC)

- Promethean Cold Storage System (CCS) was designed specifically for operation in intermittent grid and off-grid situations.
- An integrated thermal phase change material based energy storage solution (ice battery) allows operations to continue without electricity for 20h per 4h charge cycle.
- Output temperature is 4.0 to 4.5°C
- Containerized solution with a volume of approx. $18m^3$.
- The Promethean Conventional Milk Chiller (CMC) uses the same combination of vapour compression and patented energy storage solution to cool up to 1,000l of milk, of which up to 500l can be cooled per charge cycle of the thermal battery.

SolarChill:

- Originally developed as solar-PV vaccine cooler/ refrigerators; SolarChill B model for food refrigeration.
- Cold provided during the day: DC compressor, at night: natural convection from integrated ice department.
- Ice stored in compartment can provide cold for up to 3-5 days without power supply.
- Temperature interval from 2 °C to 8 °C.
- Storage compartment of about 50l / 100l-160l volume.
- Energy use: 0.76-1.01 kWh per day (at 43°C ambient temperature).
- Costs: Approx. $1,800 to $2800 for 50l vaccine cooler model (as of March 2012).

Steca PF 166/PF 240

- Chest-type DC-refrigerator designed for off-grid solar PV operation.
- Storage volume of 166l/240l.
- Variable, programmable Temperature within the range from 2 to 12°C (refrigerator) or -20 to -10°C (freezer).
- Lockable.

SunDanzer

- Standalone, containerized solar PV refrigeration solutions.
- Various sizes ($16m^3$-68 m^3)for bulk storage and commercial use.

USDA Portacooler (Kitinoja and Thompson, 2010)

- The USDA Portacooler is a build your own mobile refrigeration trailer concept - manual available
- Utilizes room-sized air conditioner (2.9 to 3.5 kW), powered by diesel generator (2 kW) and CoolBot / manual rewiring of air conditioning to be suitable for temperatures below 15°C
- Temperature range similar or same as CoolBot
- Costs: Material costs for construction of the USDA Portacooler amount to approximately $1,200 US (in US prices) but can be lowered considerably if a used air conditioning unit is used (Kitinoja and Thompson, 2010).

Sorption cooling

Product overview:

	TYPE / DESIGN	STORAGE SIZE / VOLUME	TEM-PERATURE RANGE	ENERGY RE-QUIREMENTS AND STORAGE	APPROXIMATE COSTS	REFRIGERANT
CoolChurn	Self-cooling milk can	10-20l	4°C-6°C	Thermal energy (350°C); 12-24h of cooling per charge cycle	Not specified	Natural (zeolite-water)
Solar Polar	Cooling modules	Various	Not specified	Solar thermal (evacuated tube) Thermal energy storage	Not specified	Naural (ammonia-water)
Coolar	Solar adsorption cooling	180l	4-8°C	Thermal energy 520 kWh/a / ~60W (80°C)	Not specified	Distilled Water

CoolChurn

- Milk churn with zeolite-water-adsorption cooling unit, designedfor pre-cooling and transport cooling
- Provides cold at push of a button
- Must be recharged after each use (recharging requires temperatures of about 350°C)
- Cools milk within 3-4 hours and keeps it cold for up to 12 hours
- Stores up to 15l of milk

SolarPolar

- Modular solar ammonia-water adsorption system designed for off-grid operation
- Solar thermal energy from evacuated tube collectors
- No moving parts and no electricity required
- Thermal energy storage
- System is currently still under development

Evaporative Cooling

Product overview:

	TYPE / DESIGN	STORAGE SIZE / VOLUME	TEMPERATURE RANGE	ENERGY REQUIREMENTS AND STORAGE	APPROXIMATE COSTS	REFRIGERANT
Charcoal cooler	Walk-in cold room / chest type cooler	Various sizes from few kg (mobile solutions) to several tons (fixed solutions)	Varies strongly, depending on outside temperature and humidity No less than approx. 15°C	No energy input required Optional use of low voltage DC/ AC electric pumps and fans	Build your own	Water (frequent refills required)
MittiCool Fridge (clay fridge)	Small household refrigerator	50l	Varies strongly, depending on outside temperature and humidity No less than approx. 15°C	No energy input required	Not specified	Water (frequent refills required)
USDA Portacooler Evaporative Forced Air Concept	Refrigerated trailer	3.5 to 7.0 m3 (3,500-7,000l)	Varies strongly, depending on outside temperature and humidity No less than approx. 15°C	12/24V DC Deep cycle battery	Not specified	Water (frequent refills required)
Zeer (pot-in-pot cooler)	Chest type cooler	Various sizes, but no more than approximately 12kg of vegetables	Varies strongly, depending on outside temperature and humidity No less than approx. 15°C	No energy input required	Build your own - production cost of less than $2 US	Water (frequent refills required)
Zero sEnergy Cool Chamber (ZECC)	Walk-in cold room / chest type cooler	Various sizes, ranging from few l chest type coolers to several m^3 walk-in cold rooms	Varies strongly, depending on outside temperature and humidity No less than approx. 15°C	No energy input required Optional use of low voltage DC/ AC electric pumps and fans	Build your own - production costs starting at approx. $1 US per kg of capacity	Water (frequent refills required)

Charcoal cooler

- Uses wood, wire mesh and charcoal as primary materials.
- Mostly used for small portable household and commercial applications, but larger, fixed cooling solutions possible.
- Sometimes improved through electric fans and/or water pumps.

MittiCool Fridge (clay fridge)

- Similar concept to pot-in-pot cooler, but with an advanced design.
- Attractive miniature fridge design with see-through door.
- Up to 10l of water for evaporation or consumption can be stored in a tank on top of the fridge.
- 50l volume.
- Intended for household use.

USDA Portacooler Evaporative Forced Air Concept

- Kitinoja and Thompson (2010) describe a variation of the USDA Protacooler, utilising evaporative forced air cooling.
- This version of the Portacooler uses a small water pump (1 L/min, requiring 10 watts or less), a wet pad (Aspen fibre pad) and a 100 to 200 watt fan. Outside air is sucked in by the fan through the wet pad, where it is cooled, filtered and humidified and channelled towards the produce.
- Suitable for the transport of chilling sensitive crops under climatic conditions favourable to evaporative cooling The energy demand for a small, 3.5m3 trailer amounts to approximately 0.04 to 0.05 kWh per day or 0.07 to 0.09 kWh per day for a larger 7.0m3 trailer. This amounts to approximately 0.07-0.12kWh per ton per day.

Zeer (pot-in-pot cooler)

- Simple, portable evaporative cooler using two clay pots (one larger, one smaller) and a dampened layer of sand in between (porous material).
- Water for evaporation needs to be provided manually at intervals.
- Suitable only for small scale storage needs of households or businesses.

Zero Energy Cool Chamber (ZECC)

- Also known as double-wall brick cooler.
- Evaporative cooling chamber concept to be built from locally available materials (mostly clay bricks and sand).
- Walk-in cold rooms or chest type coolers of various sizes possible(capacities commonly from 100kg to about 6-8 tons).
- Electric fans and pumps mostly applied in larger installations.

Ice-making

Product overview:

	TYPE / DESIGN	STORAGE SIZE / VOLUME	TEMPERATURE RANGE	ENERGY REQUIREMENTS AND STORAGE	APPROXIMATE COSTS	REFRIGERANT
ILK Solar Ice Maker	Crushed ice (vapour compression)	250kg of crushed ice per day; ice storage up to 500kg	Around 0°C	Solar PV gel battery	Not specified	Not specified
ISAAC	Ice machine (absorption)	Flexible - example case: 0.2 tons	Around 0°C	Solar thermal (parabolic trough)	Approximately $7,000 US (0.2 ton model)	Natural (ammonia-water)
Manitowoc R290	Ice machine (vapour compression)	Various models approx. 100-220kg of ice per day; ice storage capacity of 36-45kg	Around 0°C	115V/230V	Not specified	Natural (R290)
Ziegra ZBE Ice Machines	Chipped ice (vapour compression)	Various models, 30-10,000 kg of ice per day	Around 0°C	230V	Not specified	Halogenated (R-404A) or natural (R290)

ILK Solar Ice Maker

- Solar ice machine for application in small- and medium-scale fishery.
- Production volume: 250kg of crushed ice per day.
- Gel battery for energy storage.
- Up to 500kg of ice storage.
- UV water disinfection.

ISAAC (Intermittent Solar Ammonia Absorption Cycle) Solar Ice Maker

- ISAAC is a two stage, intermittent adsorption ice maker that uses a parabolic through to harness solar thermal energy during the day to produce ice over night.
- Under sufficiently sunny conditions, ISAAC can produce approximately 5kg of ice per m2 of collector surface per day.
- The system requires welding, piping and sheet metal work to be done locally.
- Under favourable conditions (low wages and transport costs), costs for a system producing up to 55kg of ice per day, sufficient to cool approximately 0.2 tons of produce by 28°C, are estimated to be less than $7,000.

Manitowoc R290

- High efficiency vapour compression refrigeration cycle ice machine, using approximately 20-30% less energy than comparable ice machines.
- Uses hydrocarbon refrigerant R290.
- Various models available with daily output capacities of between approx. 100-220kg of ice per day.
- Available with ice storage capacities of 36-45kg.
- Suitable for operation at 115 Volt as well as 230 Volt.

Ziegra ZBE ice machines

- Ziegra offers a wide variety of vapour compression ice machines, ranging from small commercial systems to containerized ice plants.
- Production capacities range from 30 to 10,000 kg of chipped ice per day.
- Machines are designed for continuous operation.

References

Cano-Muñoz, G. (1991). Manual on meat cold store operation and management. Rome: Food and Agricultural Organization (FAO). Available from: *http://www.fao.org/docrep/004/t0098e/t0098e00.htm (accessed 19th August 2015).*

Cengel and Ghajar. (2015). Heat and Mass Transfer: Fundamentals and Applications. 5th edition. New York: McGraw-Hill.

Coulomb, D. (2008). Refrigeration and the cold chain serving the global food industry and creating a better future: Two key IIR challenges for improving health and environment. Trends in Food Science & Technology, 19.

Coulomb, D. (2006). Statement given by Didier Coulomb, Director of the International Institute of Refrigeration. Paris: International Institute of Refrigeration (IIR). Available from: *http://www.un.org/webcast/unfccc/2006/statements/061117iir_e.pdf (accessed 13th August 2015).*

Fox, T. (2014). A tank of cold. Cleantech leapfrog to a more food secure world. London: Institution of Mechanical Engineers. Available from: *http://www.imeche.org/docs/default-source/reports/a-tank-of-cold-cleantech-leapfrog-to-a-more-food-secure-world.pdf?sfvrsn=0 (accessed 10th August 2015).*

GIZ. (forthcoming). Rapid Loss Appraisal Tool (RLAT) for agribusiness value chains. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Glaser, B. (2012). Ice in the tropics. PV magazine. 3(6), pp.138-139.

Greenpeace (2009). Cool technologies: Working without HFCs. Available from: *http:// www.greenpeace.org/usa/assets/binaries/cool-technology-report-2009 (accessed 15th January 2016).*

International Institute of Refrigeration (IIR) (2009). The role of refrigeration in worldwide nutrition – 5th Informatory note on refrigeration and food. Paris: International Institute of Refrigeration (IIR). Available from: *http://www.iifiir.org/userfiles/file/publications/notes/Note-Food_05_EN.pdf (accessed 11th August 2015).*

International Renewable Energy Agency (IRENA). (2013). Thermal Energy Storage: Technology Brief. Available from: *https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E17%20Thermal%20Energy%20Storage.pdf (accessed 18th August 2015).*

International Renewable Energy Agency (IRENA). (2015). Battery Storage for Renewables: Market Status and Technology Outlook. Available from: *http://www.irena.org/documentdownloads/publications/irena_battery_storage_report_2015.pdf (accessed 25th August 2015).*

International ValueLinks Association e.V. c2016. Website of the International ValueLInks Association e.V. Available from: *http://valuelinks.org/manual/ (accessed 14th March 2016).*

James, S. J. and James, C. (2010). The food cold-chain and climate change. Food Research International. 43(7), pp.1944-1956.

Kader, A.A. and Rolle, R.S. (2004). The role of post-harvest management in assuring the quality and safety of horticultural produce. Rome: Food and Agricultural Organization (FAO). Available from: *http://www.fao.org/docrep/007/y5431e/y5431e00.htm (accessed 11th August 2015).*

Kader, A.A. (2009). Handling of Horticultural Perishables in Developing vs. Developed Countries. Erkan, M. and Aksoy, U. (eds.). Sixth International Postharvest Symposium, 8-12 April 2009, Antalya. Available from: *http://ucanr.edu/datastoreFiles/234-1875.pdf (accessed 12th August 2015).*

Kader, A.A. (2013). Postharvest technology of horticultural crops - An overview from farm to fork. Ethiopian Journal of Applied Sciences and Technology. 3(1), pp.1-8.

Kitinoja, L. and J.F. Thompson (2010). Pre-cooling systems for small-scale producers. Stewart Postharvest Review.

Kitinoja, L. (2010). Identification of Appropriate Post-harvest Technologies for Improving Market Access and Incomes for Small Horticultural Farmers in Sub-Saharan Africa and South Asia. Alexandria (Virginia): World Food Logistics Organization. Available from: *http://ucanr.edu/datastoreFiles/234-1847.pdf (accessed 16th August 2015).*

Kitinoja, L. (2013a). Innovative Small-scale Postharvest Technologies for reducing losses in Horticultural Crops. Ethiopian Journal of Applied Sciences and Technology. 3(1), pp.9-15.

Kitinoja, L. (2013b). Use of cold chains for reducing food losses in developing countries. La Pine (Oregon): The Postharvest Education Foundation (PEF). Available from: *http://www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf (accessed 15th August 2015).*

Knips, V. (2006). Developing Countries and the Global Dairy Sector Part II: Country Case Studies. Rome: FAO Pro Poor Livestock Policy Initiative. Available from: *http://www.fao.org/ag/againfo/programmes/en/pplpi/docarc/wp31.pdf (accessed 12th August 2015).*

Lipinski, B. et al. (2013). Reducing Food Loss and Waste. Washington, DC: World Resources Institute. Available from: *http://www.wri.org/sites/default/files/reducing_food_loss_and_waste.pdf (accessed 12th August 2015).*

Pullenkav, T. (2016). Study on the drivers and challenges for cold chain development in India [for internal use only]. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Strobel, T. (2015). Case Study: Solar Ice Making. Energy Efficiency and Solar PV concepts. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Available from: *http://www.lcore-indonesia.or.id/index.php/publications (accessed 12th November 2015).*

University of California, Davis. (2015). Recommendations for Maintaining Postharvest Quality. Available from: *http://www.postharvest.ucdavis.edu/producefacts/ (accessed 26th Februar 2016).*

Wang, L. (2014). Energy efficiency technologies for sustainable agriculture and food processing. Sustainable. Energy Efficiency. 7(5), pp.791-810.

Winkworth-Smith, C.G. et al. (2015). The impact of reducing food loss in the global cold chain. Nottingham: The University of Nottingham. Available from: *http://www.naturalleader.com/wp-content/themes/natlead/images/UTC%20Nottingham%20Report_3-30_FINAL.PDF (accessed 13th August 2015).*

Winrock International. (2009). Empowering Agriculture: Energy Options for Horticulture. Washington, DC: United States Agency for International Development. Available from: *http://www.ucce.ucdavis.edu/files/datastore/234-1386.pdf (accessed 17th August 2015).*

Yahia, E.M. (2010). Cold Chain Development and Challenges in the Developing World. Erkan, M. and Aksoy, U. (eds.). Sixth International Postharvest Symposium, 8-12 April 2009, Antalya. Available from: *http://www.elhadiyahia.net/wp-content/uploads/pdf/Refereed%20Articles/Yahia.2010.Cold%20chain%20develop.%20in%20DC-AH877.pdf (accessed 12th August 2015).*

Other useful links

- energypedia – Cold storage of Agricultural Products: *https://energypedia.info/wiki/Cold_Storage_of_Agricultural_Products*
- energypedia – Cold storage for fruit and vegetables in India: *https://energypedia.info/wiki/Small-scale_Cold_Storage_For_Fruit_and_Vegetables_in_India*
- energypedia - Pre-cooling of agricultural products: *https://energypedia.info/wiki/Pre-cooling_of_Agricultural_Products*
- GIZ Proklima: *www.giz.de/proklima*
- Green Cooling Initiative: *www.green-cooling-initiative.org*
- Powering Agriculture: *http://poweringag.org/*
- Renewable Energy Component of the Indo-German Energy Programme (IGEN-RE): *http://www.igen-re.in/*
- Co- & Trigeneration Guide: *https://www.giz.de/fachexpertise/downloads/giz-2016-en-fachexpertise-energy-CoTrigenGiude-low.pdf*

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