## Project title

# Technical Assistance on clean and energy efficient cooling solutions for livestock value chains in Bangladesh

*Version 2*

| ***Activity 3*** | ***Preparation of Policy notes, and practical guidance note*** |
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| ***Deliverable description*** | ***The consortium shall prepare a final report on clean efficient cooling and good operational practices. The guidance note will provide global recommendations for WB operational teams engaged in livestock operations*** |
| ***Activity lead*** | ***IIR*** |
| ***Deliverable author(s)*** | ***All partners*** |

| ***Quality Assurance*** | | |
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| ***Action*** | ***Performed by*** | ***Date*** |
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# Nomenclature

| | |
|---|---|
| AC | Air conditioning |
| ACES | The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain |
| AI | Artificial insemination |
| BDSA | Bangladesh Dairy Science Association |
| CaaS | Cooling-as-a-Service |
| CAPEX | Capital expenditure |
| $CO_2$ | Carbon dioxide |
| COP | Conference of the Parties |
| DLS | Department of Livestock Services |
| FAO | Food and Agriculture Organization of the United Nations |
| GHG | Greenhouse gas |
| GSM-USSD | Global system for mobile - Unstructured supplementary service data |
| GWP | Global warming potential |
| HCFC | Hydrochlorofluorocarbon |
| HFC | Hydrofluorocarbons |
| HFO | Hydrofluoro olefin |
| IIR | International Institute of Refrigeration |
| IPCC | Intergovernmental Panel on Climate Change |
| JLG | Joint liability group |
| K-CEP | Kigali Cooling Efficiency Program |
| LCA | Life cycle assessment |
| LDDP | Livestock and dairy development project |
| LIC | Low-income country |
| LSP | Livestock service provider |
| MARR | Minimum acceptable rate of return |
| MEPS | Minimum energy performance standards |
| MFA | Mobility for Africa |
| NCPs | National cooling plans |
| NDCs | Nationally determined contributions |
| NGO | Non-Governmental organization |
| ODP | Ozone depletion potential |
| OPEX | Operating expenditure |
| PAYGo | Pay-as-you-go |
| PKSF | Palli Karma-Sahayak Foundation |
| PV | Photovoltaic |
| RES | Renewable energy sources |
| SDGs | Sustainable development goals |
| SEC | Specific energy consumption |
| SEforALL | Sustainable energy for all |
| SIC | Standard industrial classification |
| SNF | Solid-not-fat |
| ToT | Training of trainer |
| TRU | Transport refrigeration units |
| VMCC | Village milk collection centres |

# How does one advocate for clean cooling?

## Why apply clean cooling?

The cooling sector produces more than 7% of the total global greenhouse gas (GHG) emissions. As global temperature increases, the demand for cooling (AC and refrigeration) will increase and the emissions from these technologies will have increasing impact creating a negative cycle of increasing emissions and increasing global temperature. This cycle needs be broken by a transition to clean energy and clean cooling technologies that are available and accessible for all countries to be able to meet their sustainable development goals (SDGs). This requires not just a technological approach, but also policy, regulation, and commercial incentives as well as the need for a philanthropical approach.

In developed economies, national plans are put in place to limit global temperature rise to 1.5°C (Paris Agreement, COP21). In low-income countries (LICs) access to sustainable cold chain solutions for food, medicine, vaccines and space cooling/comfort cooling are very limited. Where applied, cooling technologies are often energy demanding and apply high global warming potential (GWP) refrigerants. A challenge moving forward is to ensure that the technologies and systems applied are clean and sustainable.

Carbon emissions are generated from use of energy (indirect emissions) and from fuels used, the refrigerant itself, and food that is lost/wasted (direct emissions). It is therefore important to reduce energy/fuel use and refrigerant loss to reduce carbon emissions. Emission from food loss and waste can also be high, often 30-40% of the food produced is lost or wasted in the food chain. In LICs most of the food is lost at the start of the chain and this is due to poor logistics, lack of cooling and poor handling and practices. It is essential to limit food loss and waste as this not only contributes to carbon emissions but results in less food being available for consumption. In terms of equipment that is used in the food cold chain, the emissions associated with usage almost always dominate (usually >90% of the emissions are related to use). Manufacturing and end of life of products/equipment are also important and cannot be ignored as there is a need to not waste scarce resources and often equipment components contain harmful materials that have an impact on the environment (e.g., mercury).

## Benefits

The quality of food deteriorates from the point of harvest/slaughter. Refrigeration enables food to be stored for longer periods. All foods that are perishable benefit from refrigeration. Applying refrigeration extends the period over which foods can be stored. However, foods need to be chilled (heat removed) and then stored. Removing the heat from foods that are either at close to the ambient temperature (crops) or in the case of animals at body temperature (meat and milk) requires a lot of energy. Refrigeration is an excellent means to preserve food. However, refrigeration systems require investment and will only be beneficial if there is an adequate business model.

Developing clean, efficient and sustainable cold chains has numerous benefits for the economy, the environment and the health of the population in LICs. The cold chain has the potential to:

- Improve food security through food loss reduction and increased shelf-life of meat and dairy produce.
- Improve nutritional intake when consuming hygienic and safe dairy and meat products that would benefit the tens of millions of poor families.
- Reduce poverty by increasing the income to farmers: farmers would have the opportunity to negotiate the produce price without being time constrained, they would also increase their income by reducing food loss and increasing product quality.
- Create new jobs through upskilling of technicians and operators in the formal cold chain.
- Contribute to the economy of the country by incentivizing local production of expensive imported equipment.

- Provide enhanced food safety and assurance.

The International Institute of Refrigeration[1] (IIR) has demonstrated that the emissions related to deploying clean cooling facilities to preserve food are lower than those emitted by the food lost due to the lack of refrigeration (Sarr, Dupont and Guilpart 2021). The IIR document shows that an improved cold chain (bringing the cold chain performance in LICs to the level of developed countries would reduce food loss by 55%. The global emissions from the current cold chain are estimated to be 1,265 Mt $CO_{2eq}$ and those from an improved cold chain are estimated to be 665 Mt $CO_{2eq}$.

# How to develop clean cooling

## Needs assessment

A needs assessment is the first and foremost step of a clean cooling project. Any cooling solutions designed need to be tailored to meet the specific needs of the local community. This could also help investors and funders to understand how a sustainable cooling and cold chain project would help with people's wellbeing and meeting a list of SDGs (Birmingham 2020). A whole systems approach should be applied for assessing the needs of cooling and cold chain to improve the system efficiency, including consideration of integrating potential demand and supply of cooling across different food types that may require different storage temperatures (Evans and Peters 2021).

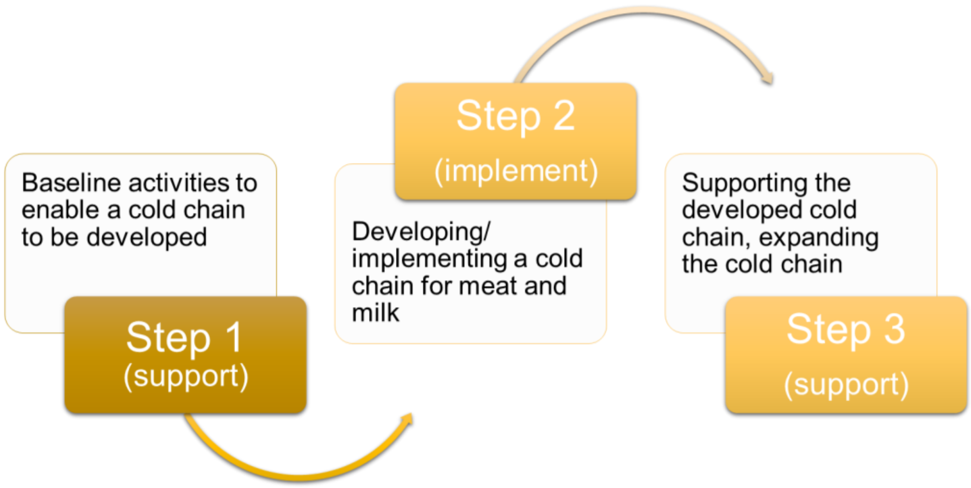
Data can be collected through questionnaires, in-depth interviews, focus group discussions and surveys from the field (Debhath, et al. 2021). The quantitative and qualitative data collected can then be analyzed to identify the present and prospective needs. Many sectors such as livestock often do apply cooling as it is an especially important sector where health, food safety and food quality are detrimentally impacted by the lack of cooling. It is particularly important in this stage to understand the local drivers and barriers affecting the uptake of cooling systems.

## Approach

To develop clean and sustainable cold chains in the livestock sector we suggest a 3-step approach where:

1. Step 1: The basic background environmental requirements for a sustainable cold chain are established to enable the cold chain to develop and flourish.
2. Step 2: Sustainable and environmentally clean technologies are applied. In all instances environmental, low carbon emission and sustainable technologies should be applied. These often have higher initial costs and so step 1 needs to establish mechanisms to support the uptake of the best and most suitable technologies.
3. Step 3: Ongoing monitoring, assessment, and improvement of cold chain activities. It is vital to review and assess the performance of the step 1 and 2 activities and adapt and adjust as necessary and as the cold chain develops. It is also vital to feel learnings from stage 1 and 2 into other projects.

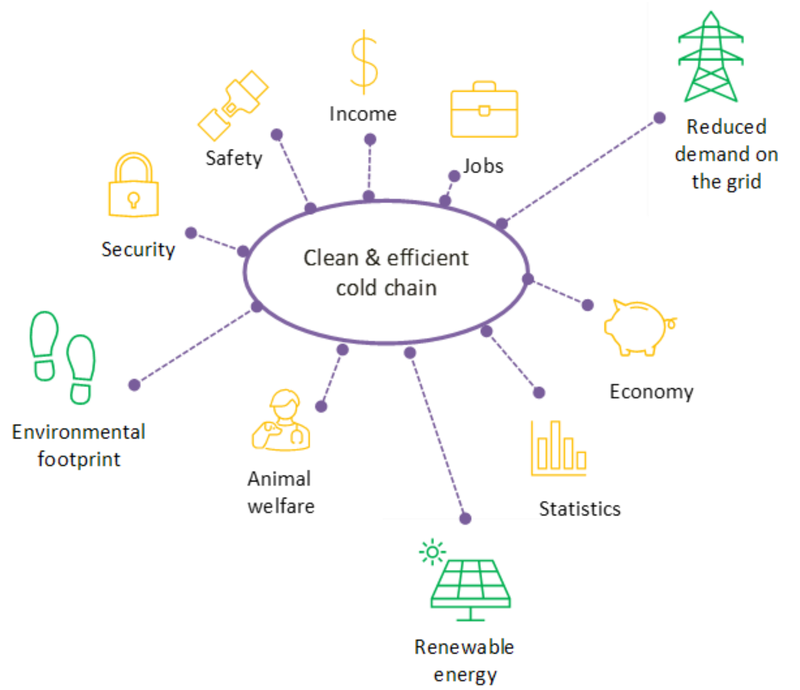
[1] The International Institute of Refrigeration (IIR) is an independent intergovernmental organisation. It is the only organisation in the world to gather scientific and technical knowledge in every sector of refrigeration. Founded in 1908, it has developed a worldwide network of leading experts. The IIR is committed to disseminating knowledge of refrigeration to improve the quality of life for all, while respecting the environment and taking into account economic imperatives.




Often the food cold chain is poorly developed in LICs and there is little appreciation of the benefits of cooling. In some cases, consumers value freshly harvested/collected/slaughtered food above food that has been refrigerated. This appears to be a historical issue where cold chain technologies may have been poorly applied in the past and so consumers lack assurance and confidence in food cold chains. Therefore, there may be a huge behavioral issue which needs to be overcome before a cold chain can be developed. This requires extensive education and marketing to explain the benefits of a cold chain to sectors of the population .

Often the major part of the food chain is informal and it uses cooling facilities for the produce with a very limited use of clean and energy efficient equipment. Although food is a key agricultural sub-sector, it generally suffers from low productivity and low-income generation in LICs. This contributes to high poverty rates among the farmers where the majority are usually micro smallholders and land-poor.

Cold chains are complex and require skilled operators and support to maintain them. Therefore, it is essential to put in place the infrastructure required to support and sustain a cold chain that is reliable and which consumers can have confidence in. Without the underpinning structures the cold chain cannot develop and grow. It is therefore vital that these initiatives are applied before any cold chain equipment is deployed as otherwise it is quite likely that equipment will not be correctly installed, managed, maintained, or operated. This will lead to failures, lack of market confidence and ultimately limited cold chain development. To facilitate this, an assessment needs to be initially carried out to determine whether a supporting infrastructure is in place. If it is not, then support should initially be provided to generate a strong network that support the cold chain. This should include:



1. Training for cold chain operators in operation and management of cold chains, health and safety, food safety and benefits of cold chain.
2. Marketing of the cold chain to consumers. The profile of the cold chain needs to be raised and consumers encouraged to consider chilled or frozen food to be a premium product rather than poor quality.
3. Education for clean cooling. Create markets for clean cooling through awareness raising of the public, consumer, and small holder farmers.
4. Training and skills for refrigeration, use of zero ozone depleting potential (ODP) and global warming potential (GWP) refrigerants suitable for purpose. Are there academic institutions or training bodies that supply accredited courses of the right level? Do citizens have access to these courses and is there a clear careers path to becoming a skilled technician? Are the benefits of a career in refrigeration clear and is there a positive case for citizens to undergo training?
5. Are there suitable courses and skills available to apply environmental and sustainable technologies such as renewable energy to operate cold chains? As most clean cold chains in LICs are reliant on renewable energy it is essential that operators have the requisite skills.
6. Overall, there needs to be a focal body within the government for the food sector. A focal body managing and overseeing the development of the cold chain is fundamental to the support activities, marketing and overseeing the development of the cold chain.
7. Often farm productivity is low in LICs. Cows produce low levels of milk and meat and land productivity is low. This is partly due to access to quality seeds, fertilizer and breeding tools, but is also an issue related to access to veterinary and agronomy support, as well as training. Often there is not a financial case that enables farmers to invest in better quality animals or production methods. Most farmers are poor. Income per person is often less than $6/day[2]. This prevents them from investing in land and horticultural or breeding assistance. The establishment of upstream services and enhanced animal welfare such as veterinary services, access to medicines and vaccines for the livestock, knowledge and understanding of standard animal husbandry practices, and access to services such as artificial insemination are required. Support is required through trade bodies, interprofessional and/or professional associations or community initiatives to convey information to farmers on the benefits of increasing productivity and the financial paybacks. Technical and financial support may also need to be provided to farmers to enable them to overcome the initial investment in technologies.
8. Are suitable trade associations/bodies or local community groups or cooperatives active in the location/area? Can supporting organizations or development partners (such as the World Bank) work though these organizations to provide support? Do these organizations have the trust and confidence of local producers and operators and so provide information and support that is valued and trusted?
9. What technologies and equipment are available? Care needs to be taken to ensure that the technologies and equipment applied are available in the country and can be sourced for a fair cost (e.g., do not incur excessive import taxes). Components to be able to maintain and repair equipment need to be available for a fair price. Are there local suppliers who can provide support? If not, are there barriers to international companies entering the market (e.g., import tariffs). Can local suppliers be encouraged to develop their market or international suppliers be incentivized to enter the market? Tariffs and taxes are very specific to a country and can make the difference between whether a cold chain is feasible or not.

[2] World Bank state that less than $3.20 per day reflects poverty lines in lower-middle-income countries, while $5.50 a day reflects standards in upper-middle-income countries (https://www.worldbank.org/en/news/press-release/2018/10/17/nearly-half-the-world-lives-on-less-than-550-a-day)

10. If cooling equipment is available within country, is it fit for purpose? If not, how will equipment be brought into the country and applied. Where should equipment be sited to provide good logistical infrastructure and links? Are personnel available with the skills and knowledge to operate the cold chain logistics?
11. Access to suitable refrigerants in country at an economic cost to end users. Often access to 'newer' refrigerants that have zero ODP and low GWPs is very restricted in LICs; if they are available, they are more costly than higher GWP alternatives. To encourage uptake and access to low GWP refrigerants there may be a need for incentives or regulation to encourage uptake of zero ODP and GWP refrigerant options.
12. An assessment of the environment around the application of cold chains. Are there appropriate incentives and levers to encourage end users to apply clean cooling?. What are the business cases and financial and business support available to provide confidence to operators to apply clean cold chains?
13. Is the physical infrastructure in place to support cold chains? Weak urban infrastructure, poor roads and traffic congestion increase travel time and create higher risks for perishable products to be physically damaged and/or spoiled. The refrigeration system on cold chain vehicles can easily be damaged leading to refrigerant loss and ultimately reduced confidence in the cold chain. Therefore, an assessment needs to be made to determine whether roads are of sufficient quality, whether water is available, whether grid electricity is available (at a viable cost) where necessary, and whether there is sufficient land available to support the development of a sustainable clean cold chain.
14. Regulation of food cold chains is often poor in LICs. Regulations either need to be developed and applied, or need better enforcement. There is usually a need for consumers and traders to have a better understanding of standards and regulations. Enforcement by government is essential as otherwise there will likely be a cost penalty for those that apply the regulations. Registration, licensing, and other requirements to operate in the cold chain sector need to be clear and simple.

## Business models

Innovative business models needs to be developed to address the financial and institutional constraints identified from the initial assessment stage, considering the initial cost, the operation and maintenance cost, the cost of training required, and the ownership and management structure.

For example, the cooling-as-a-service business (CaaS) model has been recently developed and adopted by the Global South that takes away the burden of large upfront investment, operation, and maintenance costs from the users, making access to sustainable cooling more attainable to the small and marginal farmer (KIGALI and BASE 2020). Examples of the CaaS business model include the Koolboks' solar-powered refrigerators in Nigeria, the ColdHubs' off-grid solar-powered walk-in cold room in Nigeria, and Inspira Farms' cold storage and pack houses in the UK that are supported by thermal storage systems. The examples are explained in more detail in Section "How to finance clean cooling" under 'CaaS business model'.

# What technologies are available?

Long term it is important to consider the lasting legacy of equipment which will be operated for at least a decade before being replaced. Sustainable low energy and low carbon cooling solutions should be applied. Systems will be in place for many years and so decisions made now have ongoing implications. Low GWP refrigerants should be applied, together with renewable energy powered systems.

It is therefore essential to create a detailed specification that covers current and anticipated future requirements for the cold chain to be applied. Financial support is also generally needed to enable farmers to get access to clean cooling facilities. Environmental options may have higher initial costs (but lower operating costs) and so suitable business models need to be put in place to ensure market take up. Technical support is required, and subsidies might be needed (national or international) to encourage the development of a clean cold chain as it has been shown that the capital expenditure (CAPEX) for 'green' technologies is often too high for cold chain operators.

Technologies that operate from clean renewable resources and apply ultra-low GWP refrigerants should be utilized whenever possible. This reduces environmental impact and operating costs to the operators. It is vital to consider the cold chain holistically and how the parts integrate and operate as a chain of operation from production to consumption of food.

# Technologies

## Specification

Whatever the cold chain it is extremely important to create a clear specification that encompasses the needs of the user at the start of the design process. The following need to be considered in detail:

1. How will the facility or piece of equipment be used?
2. How will it interact and integrate with downstream/upstream cold chain and cooling facilities?
3. What products need to be chilled/stored/transported?
4. How will the facilities be laid out and operated?
5. What size of facility is needed?
6. Sustainability of the cold store (components applied, GWP of refrigerant used, efficiency of operation).
7. What temperature(s) in the cold chain are required? What level of temperature control is required (temperature range and fluctuation in temperature that is acceptable)? Can foods be mixed in one room/facility?
8. Logistics of the proposed cold chain. Availability of land, access to services (water, electricity), suitability of roads/rail/waterways.

15. Safety of the facility, fire risk, risk to personnel.
16. What standards, regulations and legislation need to be applied and what are the implications?
17. What energy resources are available to operate the store (will the store be off-grid, semi-off grid, on grid)? Level of integration to allow semi or compete off-grid operation (e.g., thermal storage, batteries).
18. How much energy or resources are required to operate the facility. What are CAPEX/operating expenditure (OPEX) and return on investment/paybacks for varied options to improve efficiency.
19. What control and monitoring is required to manage the facility performance?
20. Servicing and maintenance of the facility/equipment.
21. What skills are available to operate and maintain the facility. Is additional training and skills development needed?
22. Is the use of the facility likely to change in the future and does there need to be extra capacity available to cope with increase product throughputs or changes in operation?

It is extremely important to pilot test equipment and designs within a country. A generic design or piece of equipment may not be suitable for all markets. Also, optimal solutions vary according to a country as issues such as import taxes may make the same system financially viable in one country but non-viable in another. It is important to gather information on the pilot installation and make sure that feedback is applied in future projects.

## Design of milk cold chains

Most small and medium farms that produce less than 30 litres of milk a day have no problem in selling the milk they produce. There is little benefit in them having access to chilling facilities until they increase production. Even then the price of chilled milk needs to be higher to generate new income for farmers.

Many milk chains in LICs are developed around village milk collection centres (VMCCs). Milk is brought to a central facility twice every day in the morning and afternoon by farmers or is collected by a collection service. Logistics support is often provided to the Society Managers at the VMCCs by the main processor. At the collection point the milk is tested for fat content, solid-not-fat (SNF), microbials, organoleptic, and a few adulteration tests; product is only accepted if the milk satisfies all the criteria.

The milk is chilled before being transported in insulated (non-chilled) tanker vehicles to a central processing plant for pasteurization, further processing, and packing. At all points in the cold chain the milk is tested for quality and safety. The products are then distributed to retail outlets and ultimately to the consumer (Figure 1).

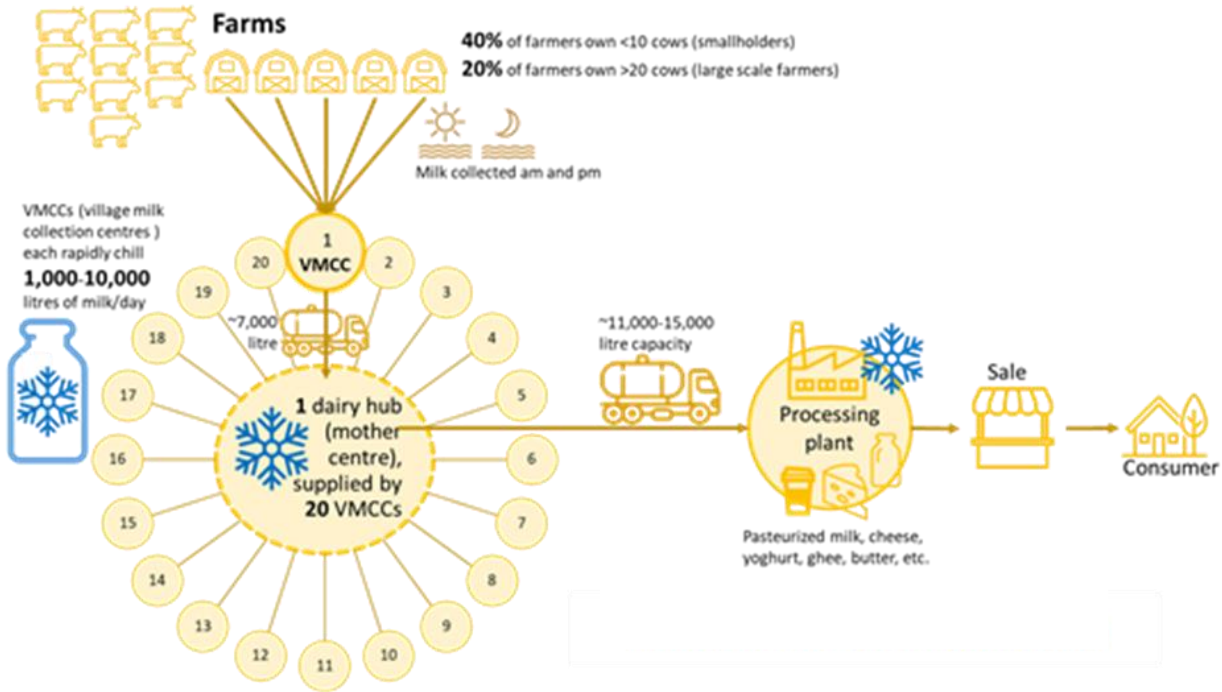



***Figure 1. Typical VMCC system and chain to the consumer.***

Refrigeration systems for milk chilling at the VMCCs may be driven directly from the grid or from renewable resources such as photovoltaic (PV) panels or a heat source. If driven from the grid or PV (or a combination hybrid approach) the systems are almost always direct expansion compression systems.

### Solar systems

The use of renewable resources is essential as many farms are off grid or semi-off grid. Solar powered milk chillers are readily available, but performance data is often limited and the systems that are available often operate using high GWP refrigerants. Both these issues need to be overcome to make systems clean and sustainable.

Evidence from GOGLA/Intellecap (GOGLA and Intellecap 2021) indicated that for India solar power milk chillers with thermal storage were the best option in terms of total cost of ownership and average cost per litre of milk over a life of 10 years for the equipment (Singh, et al. 2021). The Food and Agriculture Organization of the United Nations (FAO) has also published cost-benefit assessment of milk cooling in Tanzania and Tunisia (FAO 2018a) (FAO 2018b). In both instances they assessed biogas powered domestic milk chillers of 10 litre capacity and larger solar powered milk chillers with a capacity of 600 litres. In both cases detailed information on each system was not provided and so it is difficult to compare conclusions with the better described GOGLA study.

For Tanzania, the study concluded that biogas was better suited to the domestic system and solar to the larger system and that there were financial benefits for both systems. In Tunisia it was difficult to make a financial case for either system (due to high subsidies on electricity prices and low returns for co-products). The solar system had a slight positive internal rate of return (IRR) whereas the biogas system had a negative IRR. However, the study concluded that social and environmental factors made the investment economically positive. These FAO studies do show that situations vary between countries and local conditions have a significant impact on whether a system is financially attractive or viable.

Smaller systems are also available on motorbikes to provide collection and cooling of milk from farms. Companies such as Savanna Circuit Tech Ltd. manufacture a solar-powered milk storage tank mounted on a motorcycle that can collect 120-1000 litres of milk per journey.

## Biogas

The use of heat powered refrigeration systems is feasible. At least two companies produce systems for chilling milk (SimGas B.V. and Solar Ice Company). These systems have been demonstrated in east Africa and Kenya but there are no technical reasons why they could not be applied elsewhere. However, experience with biogas systems if often mixed with reliability issues being reported.

## Energy storage

Systems where there is an inconsistent supply of electricity (either due to an intermittent grid or use of solar panels where supply varies) generally incorporate some form of energy storage. This is most commonly either batteries or a thermal store. Use of thermal stores are an excellent option for milk chilling. Thermal storage systems used in milk chillers are often ice bank systems. Such systems generate a store of ice when energy is available that is then used when energy is not available. Use of ice bank systems or ice storage are particularly relevant to solar PV systems where there is a need for intensive ice production during periods when solar radiation is high. Generally, most milk is collected in the morning and evening whereas solar radiation is greatest during the middle part of the day. Therefore, utilizing the energy from solar power when it is available and generating ice is a means to create a thermal battery, and not have to utilize conventional battery technologies for energy storage is an efficient means to operate the system. Utilizing the latent heat of ice which is high (334 kJ/kg) is efficient compared to sensible energy storage using a fluid such as water (4.184 kJ/kg.K). This means that the thermal store can be compact and energy dense.

Ice banks systems are readily available and are commonly used to milk chillers on farms in developed countries and are used in many off grid/semi-off grid solar systems. These systems employ a refrigeration plant with an evaporator (plate or coil) immersed in a tank of water which chills the water to 0°C. During times of low load and high electricity generation from the solar panels, a store of ice is built up on the evaporator which subsequently melts to maintain temperatures during times of high load. A typical design is presented in Figure 2.

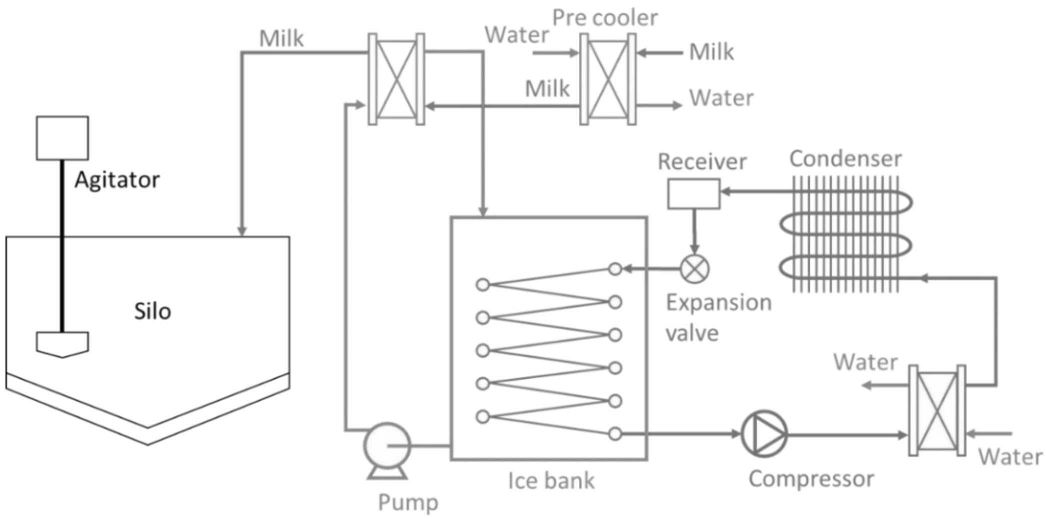



***Figure 2. Schematic diagram of an ice bank milk cooling and storage system (silo refrigeration not shown).***

## Passive systems

### *Cool churns*

A cool churn or insulated can is an option for farmers who do not produce much milk. In rural areas where there is little access to grid electricity it is possible to provide some cooling using cooling in cans. Ice is generated by a freezer located at a central hub or on the farm and used in a compartment in the can to chill milk. One of the main advantages of a cool churn is that is portable and can be transported using a bicycle or motorbike to the main cooling hub.

### *Evaporative coolers*

An evaporative cooler is a device that cools air through the evaporation of water. Several systems have been developed and shown to work. Systems are most beneficial in dry arid areas where the humidity is low. In such locations a cooler can lower an insulated chamber to approximately 10°C below the outside temperature.

# Design of meat cold chains

Few off grid meat cooling solutions are available and those that have been developed have had limited application. The main system that was developed used solid carbon dioxide ($CO_2$) pellets. This successfully and economically chilled carcasses without any direct refrigeration, but required a steady and reliable source of $CO_2$ which may not be readily available in all markets (Gigiel 1985). Alternative meat cooling systems using absorption or solar PV systems are possible but have not been extensively developed. This is mainly due to the high refrigeration loads at the start of the chilling process required to remove product heat rapidly and the lack of market demand.

Cooling products on a farm using mains electricity may not be feasible as the energy supply available may not cope with the energy intensive cooling demands required for meat. The economics of installing a cooling system on a farm is very unlikely to be feasible (even if the facility was shared between several farmers). For a small farmer the cooling a beef carcass is an activity that they may only wish to carry out every few months at most. It is not a feasible proposition to install a beef chiller for the slaughter of one or two animals occasionally. In this case it would be more practical to take the animal to a central slaughterhouse where it would be killed, chilled, butchered and stored. As the slaughterhouse would kill many animals each day, the economics of the operation would also make commercial sense.

The requirement to slaughter limited numbers of animals per day is the primary argument against small on-farm slaughterhouses and chillers. One option to overcome this is to use mobile abattoirs that can travel to different locations to slaughter animals. Often mobile abattoirs do not have chilling facilities as are used in locations where there are already some chilling facilities. Most mobile abattoirs have the capability to slaughter and chill a maximum of 10 large animals per day. The capital costs of the mobile abattoirs vary considerably and feedback from systems that have been installed (mainly in developed countries/areas including UK, Europe, America) have shown that the systems rarely are successful, and most have not been commercially viable. This is usually because there is insufficient throughput and often the logistics of the operation were not well considered. For example, information obtained for the Livestock and Dairy Development Project (LDDP) in Bangladesh has indicated that farmers would not use or appreciate mobile abattoirs in rural areas and so (for Bangladesh) this is not a recommended option currently.

## Available systems

Most meat is chilled or frozen in refrigerated air blast chillers where air is blown over the carcass to remove the heat (Figure 3). This can be a single or 2-stage (or more) process. The carcasses may be loaded into a chiller/freezer and then be chilled or frozen in a batch system. Alternatively, they may be attached to a moving chain which moves the carcasses through a cooling chamber. The advantage of this system is that all carcasses pass though the exact same process and so cooling rates are more uniform.

Most systems apply air as the chilling fluid because it is flexible, hygienic and is relatively non-corrosive to equipment. Air chilling or freezing produces much lower rates of heat transfer than contact or immersion technologies. However, this may not be a major issue since conduction within products such as meat is often the rate-controlling factor. Most of the factors that control the chilling process are common to all species. Air temperature, air velocity, and to a limited extent, relative humidity, are the environmental factors that affect the cooling time for meat carcasses. Cooling rate is affected by the weight and dimensions of the carcass as well as fat cover for fatty meats.

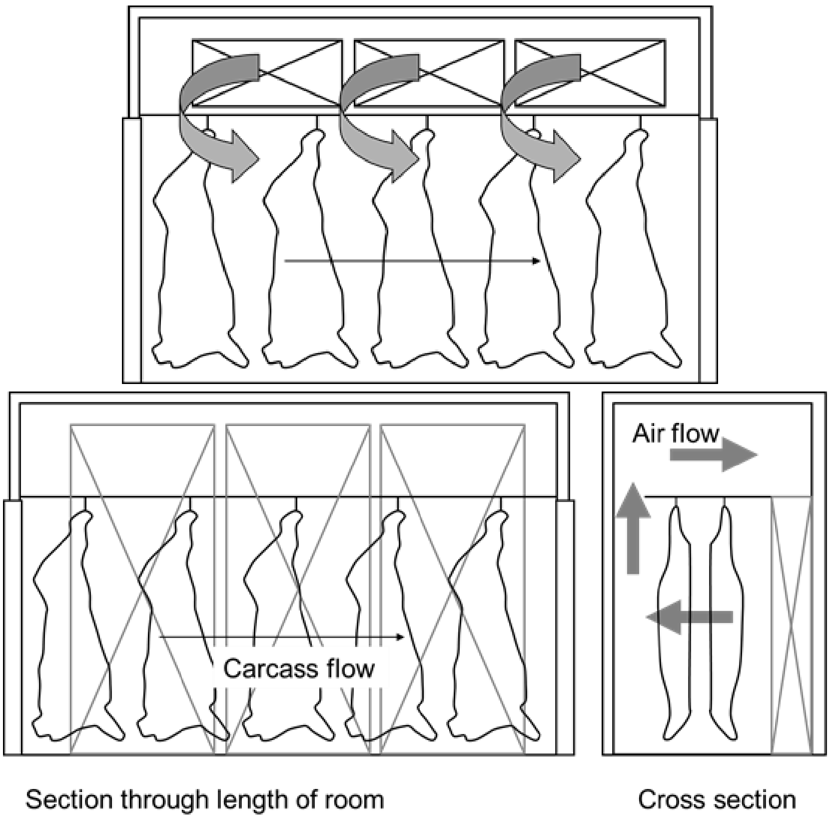



***Figure 3. Static (top) or tunnel (bottom) chiller/freezer for meat products.***

Once chilled, meat is then often butchered into primals or joints and packed for distribution. Sometimes the meat may be processed into other products such as burgers, sausages or cured, or may be frozen. These processes may be carried out at the primary chilling facility but are more commonly carried out in a secondary processing facility.

Transportation between primary, secondary, and potentially other processing and packing facilities is via refrigerated distribution vehicles. Cold stores are used to maintain the meat at the correct low temperature between processing stages. Ultimately the meat is distributed to professional kitchens with refrigerated storage cabinets or retail outlets with refrigerated display cabinets for sale of products to consumers.

### Control and monitoring

When installing new cold chain equipment, the use of remote monitoring (including predictive maintenance) and control of performance should be considered. If these items are not considered systems may fail and the confidence of the users may be reduced.

## Refrigerants

Refrigerant selection is an important issue in terms of environment, safety, and suitability. Refrigerants with long term sustainability should be selected that have zero ODP and ultra-low or low GWP. The ODP and GWP impacts of refrigerants are only apparent if systems leak refrigerant.

1. Local regulations and agreements should be considered. Most LICs are Article 5 countries[3] which fall into the following groups (UNEP 2016) with the schedule outlined in

Table 1:

2. Article 5 Group I: 136 developing countries that make up all Article 5 countries as specified under the Montreal Protocol, with the exception of Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates (UAE).
3. Article 5 Group II: The ten listed countries from 1 which are characterized by high ambient air temperatures and make up a second and separate group of Article 5 countries.

***Table 1. Phase down schedule for article 5 countries[4].***

| | **Article 5 Parties: Group I** | | **Article 5 Parties: Group II** | |
|---|---|---|---|---|
| **Baseline years** | 2020, 2021 & 2022 | | 2024, 2025 & 2026 | |
| **Baseline calculation** | Average production /consumption of HFCs in 2020, 2021, and 2022 plus 65% of HCFC baseline production /consumption | | Average production /consumption of HFCs in 2024, 2025, and 2026 plus 65% of HCFC baseline production/consumption | |
| Reduction steps<br>Freeze | 2024 | | 2028 | |
| Step 1 | 2029 | 10% | 2032 | 10% |
| Step 2 | 2035 | 30% | 2037 | 20% |
| Step 3 | 2040 | 50% | 2042 | 30% |
| Step 4 | 2045 | 80% | 2047 | 85% |

[3] List of Parties categorized as operating under Article 5 paragraph 1 of the Montreal Protocol (considered as developing countries): https://nou.gov.pk/montreal-protocol/article-5-parties/

[4] Background information on calculations and article 5 requirements can be found at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjL1e7Rr-L5AhXoQUEAHdFlAc4QFnoECAYQAQ&url=https%3A%2F%2Fassets.researchsquare.com%2Ffiles%2Frs-948327%2Fv1%2Fc85b36fc3e0bfa34c65eefd3.docx&usg=AOvVaw16Es5KXqIlEP4qAEW1bzXz

Off grid systems should use ultra-low/low GWP refrigerants. Although systems are available, the choice is small. Established manufacturers need to be encouraged to move to low GWP alternatives and support (technical and financial) provided where necessary.

Refrigerants are classified according to their type. Most refrigerants in use in LICs are hydrochlorofluorocarbons (HCFCs) or hydrofluorocarbons (HFCs). Occasionally other newer refrigerants such an hydrofluoro olefins (HFOs) may be applied or natural refrigerants such as hydrocarbons, ammonia (R717) or carbon-dioxide (R744).

Most HCFC refrigerants have been withdrawn from the market due to their ODP. The exception is R22 (HCFC-22) which is an HCFC and has an ODP of 0.05. HFC refrigerants are widely applied but generally have high GWPs. R404A (HFC-404) which is widely used has a GWP of 3922. Many currently available chilling systems use R404A or R134a. R134a has a much lower GWP (1430) than R404A but is higher than would be legally allowed for systems in Europe.

Efficiency should be considered when selecting an alternative refrigerant. If systems are optimized there is usually less that a ±10% variation in efficiency for a given cycle (Institute of Refrigeration 2021). The overall system design (e.g., type of cycle, heat exchanger design, compressor selection and control strategy) can have a far greater impact on system efficiency than the choice of refrigerant.

A large selection of refrigerants are available. There is no reason why smaller direct expansion systems cannot be operated using a hydrocarbon refrigerant. Systems must be checked for safety as hydrocarbons are A3 refrigerants and flammable. Larger remotely operated systems which would be used in slaughterhouses often use R717 which is toxic and flammable but has a GWP of 0.

## Maintenance and servicing

The ability for equipment to be serviced and maintained should be assessed as it is critical.

In all cases when applying alternative refrigerants, it is essential that the market is ready, and operators and service engineers are trained. Access to some of the new refrigerants and their cost is also often an issue in LICs and so there must be incentives or regulation to ensure that there is market pull for the refrigerants to be applied.

Consideration should also be given to maintainability. Many systems which may be installed might be in relatively remote locations. This adds time and complexity for technicians to attend to correct issues that develop. Unless systems can be repaired rapidly, this may lead to breakdown and reduced confidence in systems by farmers and end users, which may result in failure of take up the application of refrigeration technologies. Advanced remote control and monitoring is a means to overcome these issues as issues can be assessed remotely and fall off in performance highlighted at an early stage (predictive maintenance).

Training to use lower global warming potential (GWP) refrigerants (in particular, A2L and A3 refrigerants) is required as well as skills to repair and optimize the performance of cold chain equipment. Formal training for engineers is needed as well as skills development in the local refrigeration industries.

## Demonstration and communication

It is important that stakeholders see examples of technologies, systems and processes that are applied. Feedback from users is important to generate confidence in the clean cooling systems applied. Examples of case studies, visits to sites, social media posts and publicity around successful installations is important to ensure confidence and take up of technologies. Examples of business models and how they were applied and benefited end users is essential to show that clean cooling is a feasible opportunity that has financial benefits for users.

# How do we train stakeholders?

The major stakeholders in the dairy and livestock sector in LICs include policymakers from the government, local government officials, farmers and producer groups, local buyers, equipment importers/sellers, energy providers, meat and dairy private sector entities/processors, non-Governmental organizations (NGOs), and international development agencies. In terms of the use of the cold-chain technologies in the sector, the list can be narrowed down to those stakeholders who directly take part in the specific product value chains e.g., individual milk producers and producer groups, collectors and processors in the informal and formal milk sector, cold-chain equipment importers, manufacturers and sellers, and the consumers.

The use of cold-chain technology in the milk sector in LICs is generally well-established in the formal sector and to a smaller extent in the informal sector. This provides an opportunity for capacity building regarding cold-chain technologies for those working in this sector. In contrast, the meat sector has hardly seen any use of cold-chain equipment and hence the training requirement for this sector is yet to be realized.

The training requirements of the stakeholders can be grouped into the following categories:

1. Awareness and motivation on the use of cold-chain technologies in the particular product sector,
2. Use and maintenance of the existing cold-chain equipment,
3. Sustainable alternatives for cooling solutions, and
4. Selection of cooling solutions.

## Training on awareness and motivation on the use of cold-chain technologies

There is often a lack of awareness among most of the public regarding food hygiene in LICs. The need for immediate cooling of milk and meat is not well understood by a large fraction of the producers, processors, and consumers. The chilled products are sold at a lower price than usual in the informal dairy and meat sectors. Awareness development among the key stakeholders is an absolute necessity to motivate the stakeholders to invest in cold-chain technologies.

## Training in the use and maintenance of existing cold-chain equipment

The meat and dairy sectors in developing economies are dominated by the informal sector with a small formal sector. For example, only one-tenth of the milk sector in Bangladesh operates formally with the use of cold-chain equipment at various stages of collection, transportation, and processing. Since the formal sectors are usually still being developed, the equipment in use (mostly in the formal sector with a few exceptions in the informal dairy sector) varies widely in terms of technology, age, refrigerant-in-use, and operational practices.

Training for those who frequently use cold-chain equipment for chilling meat or milk may include:

- Basic operation of refrigeration systems: vapor compression and absorption refrigeration cycles,
- Refrigerants: their classification, preliminary concepts of ozone depletion and global warming,
- Assessment of refrigeration systems using indexes such refrigeration duty (kW), performance (energy use per day/year), energy use per facility volume (kWh/m$^3$/day)'
- Simple maintenance of refrigeration systems,
- Fault identification, diagnosis and repair, and
- Best practices and case studies including preliminary concepts on risk assessment and standard operating procedures.

The corresponding ministry/department may collaborate with individual large operators to conduct in-house training for their engineers/technicians responsible for the operation and maintenance of cold-chain equipment.

## Training on sustainable alternative for cooling solutions

The refrigeration equipment in most LICs is often powered by fossil-fuel powered electricity. The equipment also uses refrigerants such as R22, R404A, etc.

Local manufactures, importers and service engineers need better understanding of sustainable alternatives to current practices and what benefits they bring. The training may include:

- Refrigeration systems for chilling and freezing of foods,
- Components of refrigeration systems and their impact on the performance of the refrigeration systems,
- Use and design for application of flammable or mildly flammable refrigerants (A3 or A2L refrigerants),
- Use and design for application of natural refrigerants such as R717 and R744,
- Load calculation for a refrigeration system,
- Causes of inefficient operation of refrigeration units and ways to improve energy efficiency,
- Environmental and climate change impacts: direct and indirect ,
- Regulations on refrigerants,

Incorporation of sustainable alternatives: renewable energy sources such as solar PV and biogas, use of thermal storage, etc. This high-level training requires engineering knowledge and prior experience in the business and operation of cold chain equipment. The corresponding ministry/department may need to enlist several training facilitators with expertise on sustainable refrigeration system from academia/industry for the purpose of the training.

## Training on selection of cooling solutions

Selection of cooling solutions is a business decision that the owners and operators must make. For an informed decision, one needs to know what the alternatives in terms of cold-chain equipment and its energy sources are, how much the individual system costs, what are the added benefits (quantitative and qualitative) of switching from one technology to the other, and the return on the investment.

This training is intended for policy makers from the relevant government offices, medium- and large-farm owners, milk collectors, formal food processors.

The training may include:

- Available business models for cooling solutions for the dairy and meat sectors.
- Basic concepts used in economic decision making: CAPEX, OPEX, payback period, minimum acceptable rate of return (MARR), internal rate of return, etc.
- Available technologies, their advantages and disadvantages for different locations and situations.
- Methods of comparing financial viability of technical alternatives and decision making.

## Summary of training needs

Table 2 summarizes the training requirements that should be applied in LICs to develop clean efficient cold chains.

*Table 2. Summary of training needs in LICs.*

| Training category | Content | Target group | Responsibility |
|---|---|---|---|
| **Awareness and motivation on the use of cold-chain technologies** | Food hygiene and need for chilling/freezing of milk and meat | Small farmers<br>Producer groups | The corresponding ministry/department |
| **Use and maintenance of the existing cold-chain equipment** | Basic operation, refrigerant, performance assessment, simple maintenance, best practices | Cold-chain equipment operators<br>Maintenance engineers/technicians | The corresponding ministry/department |
| **Sustainable alternative for cooling solutions** | Overview of refrigeration systems, load calculation and design, efficiency opportunities, environmental and climate impact, regulations, sustainable alternatives | Cold -chain equipment manufacturers, importers, sellers<br>Service Engineers | The corresponding ministry/department |
| **Selection of cooling solutions** | Business models, basic concepts in economics, comparative financial assessment | Policy makers, large-scale operators, and processors | The corresponding ministry/department |

# How to finance clean cooling?

## Potential business models

Potential business models include CaaS, Pay-as-you-go (PAYGo), community-based shared-use, and Guarantee funds to end-use finance (Efficiency for Access 2021).

### CaaS business model

Energy efficient cooling systems are cheaper over the longer term considering the cost of electricity, maintenance, equipment, and water, but business owners or cooling users are not investing in more efficient systems due to the higher upfront cost of efficient technology.

CaaS is a pay-per-use model, in which the service of cooling is provided without selling the equipment (Birmingham 2020) (KIGALI and BASE 2020). The key actors involved are cooling users, technology providers and investors. Under CaaS, the technology providers own the equipment, and are responsible for providing equipment and maintenance, and paying for energy and water bills. There is no transfer of ownership of the equipment at any stage, which motivates the technology providers to upgrade or repurpose old equipment if they could reduce the operation and maintenance costs or generate new revenue. Investors gain repayment from the technology provider. Users do not pay for the capital cost of equipment, but instead pay per use of it. Therefore, CaaS could take away the burden of large upfront investment, operation, and maintenance costs from the users, making access to sustainable cooling more attainable. It also reduces failures in the cold chain as the technology provider is responsible for the operation and maintenance. CaaS could be an effective model to involve the private sector to complement the supply chain and leverage private capital towards energy resilience and sustainable cold-chain solutions.

The CaaS model has been used for solar-powered refrigerators by Koolboks in Nigeria. Koolboks' CaaS model focuses on decentralized cooling solutions including solar-powered cooling and freezing services to commercial customers and health centres and pharmacies. They use remote temperature monitoring and alarm functions for critical medicines and vaccines (Efficiency for Access 2021). Among existing trials, the service provider can typically recover investment costs after approximately three years of usage (Efficiency for Access 2021). ColdHubs in Nigeria has also offered a pay-as-you-store model to farmers for the usage of an off-grid solar-powered walk-in cold room which they install and maintain. ColdHubs positions their facilities close to farm clusters and markets and charges a fee for every 20 kg stored in their cold room per day (Brown 2020) (Carbon Trust 2020). In another example, Inspira Farms in the UK designs and finances portable cold storage and pack houses, which are either grid connected or powered by solar PV and supported by thermal storage systems. Inspira Farms offers a pay-as-you-chill model to users in some markets, according to the volume and type of product stored (Carbon Trust 2020).

In LICs, the service providers could work with finance providers, local distributors, technical partners and legal partner to establish and benefit from a CaaS business model.

## PAYGo platforms

The PAYGo platforms have been used for digital software enabling PAYGo technologies in South Africa. The platforms are used for equipment connectivity to enable remote performance monitoring, preventive maintenance, and the creation of credit histories for customers that could facilitate their access to finance. Traditional PAYGo models require providers to develop their own software solutions, which is a barrier for many small and medium-sized equipment providers. New innovate PAYGo models, for example developed by Solaris Offgrid and the Indian fintech company KPay, use an interoperable PAYGo solutions that can be embedded into a broad spectrum of electric equipment and does not require the end user to have a smartphone or internet access. The cooling equipment needs to be equipped with a small microchip, which enables remote communication with a centralized control centre. The service provider can switch off the equipment remotely if the customers do not pay.

KPay in India developed a digital PAYGo platform, which enables consumers to use and pay overtime based on individual needs through a global system for mobiles - Unstructured Supplementary Service Data (GSM-USSD) codes or digital-payment gateways (Efficiency for Access 2021). Also using an online app, EcoZen in India has sold their off-grid solar cold room into Kenya, for which they use internet-enabled sophisticated remote monitoring equipment to enable efficient on-farm cooling (Brown 2020).

## Community-based shared-use model

The shared-use community-based distribution model has been adopted to deploy electric vehicles in Zimbabwe and is combined with a service model in use. Different from the CaaS model, the community based shared-use model distributes the equipment on the basis of a shared use and community-based ownership. The shared-use model can be combined with rentals or lease-to-own options.

The community-based shared-use model has been used by Mobility For Africa (MFA) in rural Zimbabwe. MFA manufactures and supplies electric tricycles to productive groups in rural areas, where MFA also invests in off-grid charging stations, trains customers how to use the electric tricycles and provides maintenance services (Efficiency for Access 2021).

## Guarantee funds for end-use finance

The risk guarantee fund minimizes the probability of non-repayment for the banks by mitigating the customer's underlying credit risk. The guarantee funds typically cover 50%-70% of the loan value, connecting to the purchase of an asset (equipment). The service provider (company) provides client-education and loan facilitation services by taking responsibility for both collection and the creation of the farmers' aggregated joint liability group (JLG) as part of their distribution and sales processes. The company carry out work on customer profiling (initial due diligence and identification of appropriate customers) to help understand the actual level of risk for financial institutions, which enhances their trust in farmers and technologies.

The creation of JLG enables farmers in the group to share the financial burden and benefits, and collectively make contributions towards repayments. This model overcomes the barrier of the low risk tolerance of financial institutions who require farmers to provide collateral in order to mitigate their credit risk. This approach has been used by Punam Energy for solar water pumps in India. Punam Energy developed a strong relationship with banks and financial institutions that reduced the risk associated with small and marginal farmers. Punam Energy also provides client-education and loan-facilitation services as part of their distribution sales processes, where they take responsibility for collection and creation of the JLG.

## Example of recommended business models (the case in Bangladesh)

It is essential to mobilize private capital to invest in the livestock cold chain system through novel business models such as CaaS that could potentially be deployed in emerging markets (PATH and World Health Organization 2011) (KIGALI and BASE 2020).

For example, Bangladesh has a total cattle and buffalo population of 25 million of which 95% is dairy and beef cattle, and 5% is buffalo. Goats contribute over 5% of total production, but mostly for home consumption and rearing offspring. Total milk production is approximately 5 m MT, of which 15% is for home consumption, 80% is informally traded and 9% is collected and processed by dairy companies. The livestock sector in Bangladesh faces several challenges including limited genetic potential of animals, feed constraints, associated loss of land due to climate change, pervasive animal health challenges compounded by the high densities of livestock in the region. Small, scattered farmers lack access to input, advisory and financial services and output markets and the majority of production goes through informal markets where food safety and adulteration challenges abound.

The Bangladesh dairy and livestock cold chain could adopt business models combining CaaS and PAYGo solutions. The business models would be shared-use based model for small groups of smallholder and marginal farmers who need help most according to the Bangladesh Dairy Science Association (BDSA) and Palli Karma-Sahayak Foundation (PKSF) (PKSF 2021). The business models could be used to establish milk collection points in villages with cooling facilities and cold-chain logistics (vehicles with cooling function).

There is also an opportunity and strong market to establish facilities to make dairy by-products as an additional income generating activity. The establishment of food processing in villages would benefit from buyback options offered by the system provider to guarantee purchasing the by-products from the farmers. The WB supported by LDDP in Bangladesh could provide guarantee funds to reduce risks faced by financial institutions and thus mobilize loans to smallholder farmers who lack credit histories or collateral (LDDP 2021). The business models should also include capacity building training. Training will need to be provided to the equipment users on key topics such as increasing the quality and quantity of milk produced, and the use of cooling and cold chain.

# What are the policy actions that need to be taken to create a conducive framework for clean cooling?

The increasing demand for cooling has contributed significantly to global warming and climate change. Conventional cooling equipment, such as refrigerators and air conditioners, industrial-scale chillers and other devices, account for around 10% of all GHG emissions (UNEP 2019). This is mainly due to HFCs, other refrigerant emissions, and fossil fuel-based energy powering the cooling equipment (IEA, World Energy Investment 2020, Paris: International Energy Agency 2020) (UNEP and IEA 2020).

In October 2016, more than 170 countries signed the Kigali Amendment, an amendment to the Montreal Protocol on Substances that Destroy the Ozone Layer (Montreal Protocol), committing to phase down HFCs by cutting their production and consumption in order to protect the climate and the ozone layer (UNIDO 2017). The goal is to achieve more than an 80% reduction in HFC consumption by 2047. The Amendment entered into force on 1st January 2019, and the Parties have made a series of actions to improve the energy efficiency of cooling equipment in parallel with the switch from HFCs to more climate-friendly refrigerants. The action under the Amendment will avoid up to a 0.5 °C increase in global temperature by the end of the century (EPA 2021). Figure 4 shows the HFC phase-down timeline according to the Amendment.

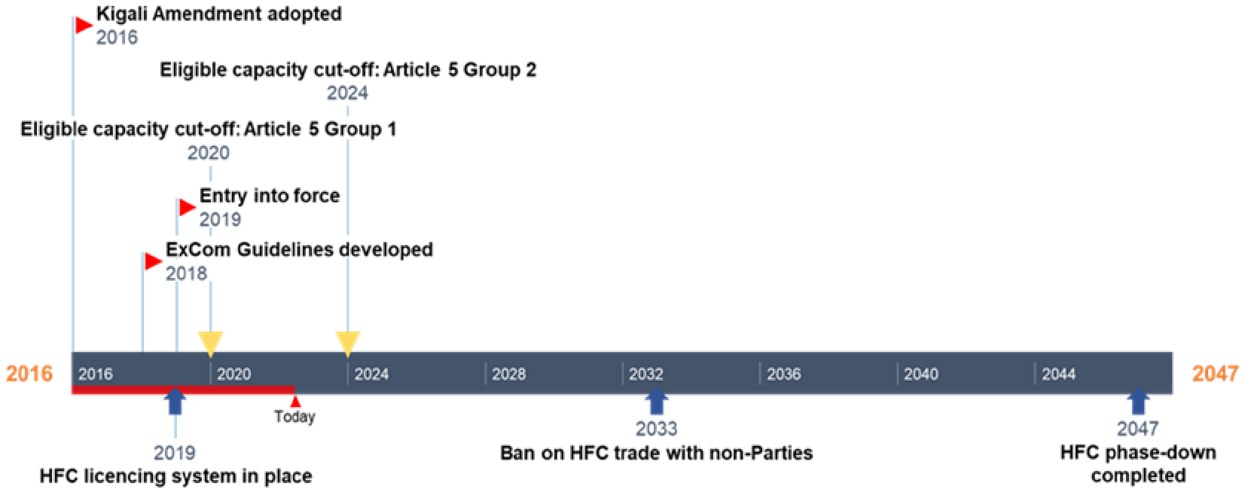



***Figure 4. The Path from Kigali: HFC phase-down timeline (UNEP n.d.)***

Despite the strong ambition to transition to clean cooling, cooling growth is threatening the clean energy transition. Hence, it is not possible without further policy actions to create a conducive framework for access to clean cooling for an overheating world.

# Required policy actions

Policies that enhance access to clean cooling are identified within governments' climate pledges and national plans, specific energy performance standards and energy efficiency labelling, tax incentives for clean and efficient cooling equipment, mobilizing public and private funds to invest in clean cooling technology and bridge the affordability gap, and international corporation enhancement. Specifically, several policy actions can and should be taken by governments to expand the sustainability and coverage of clean cooling.

## Incorporating clean cooling into government climate pledges and national plans

Governments play a significant role by incorporating clean cooling into their climate pledges, such as their nationally determined contributions (NDCs) and national cooling plans (NCPs), which include consideration of the Montreal Protocol and Kigali Amendment commitments, as well as energy efficiency and access to cooling as development priorities. Governments could also ensure that sustainable cooling considerations are included in energy, urban, transport, agricultural, and health service projects.

Clean cooling is an area with untapped mitigation potential that could be used to boost the overall mitigation ambition of NDCs. The Kigali Cooling Efficiency Program (K-CEP) has produced a guide to support policymakers in considering the role of efficient, clean cooling in their NDCs ahead of the 2020 round of NDC revisions (K-CEP, Guidance on Incorporating Efficient, Clean Cooling into the Enhancement of Nationally Determined Contributions 2019). Many countries have already included cleaning cooling in their original NDCs, and at least 27 countries have developed or are working on NCPs. The industry is responding with more sustainable, climate-friendly technologies, cooling services, and innovative space cooling approaches are less dependent on energy-intensive electrical cooling.

In terms of cold chains, for food or vaccines, governments are recommended to conduct a cooling needs assessment for a country's baseline for access to cooling, through tools like Cooling for All Needs Assessment (SEforAll and Heriot-Watt University 2019)[5]. The existing capacity and demand, and future needs should be established in order to identify gaps, shortfalls, and opportunities within a cold chain (Clean Cooling Collaborative 2021). Policymakers can therefore measure the full scope of cooling demand, and then understand what policy, technology, and finance options are required.

## Implementing minimum energy performance standards and energy efficiency labelling

Improving the cooling equipment efficiency has the potential to more than double the climate benefits of the Kigali Amendment, with the combined potential to avoid the equivalent of up to 260 billion tons of carbon dioxide by 2050 (IEA and UNEP 2020). A dual strategy to make cooling more environmentally friendly and energy efficient has the potential to reduce the projected global temperature increase by 1°C over the next few decades (Voopic and J. & T 2020).

Governments can impose minimum energy performance standards (MEPS) and labelling schemes for refrigerated equipment, encouraging manufacturers to improve the energy efficiency of their cooling products and lower the global warming potential (GWP) of refrigerants to meet or exceed Montreal Protocol obligations. Introducing efficiency standards could improve the energy performance of air conditioners by 50%. This would also help keep cooling on track with the Net Zero Emissions by 2050 goal. However, despite their effectiveness, many countries still have weak, inadequate, or non-existent MEPS for cooling technologies compared to global best practices (Cava 2022).

In addition, maintaining cold chain conditions is an energy-intensive endeavor. Therefore, gradually developing and implementing practices and technologies that achieve the energy savings of cold chain would be recommended (Estrada-Flores 2010). For instance, preventive maintenance, review of refrigerated equipment standards, certification processes, food safety standards and maximum safe temperatures for cold chain management could be considered at an early stage.

The implementation of new energy labelling and MEPS in all links of the chain, the introduction of alternative refrigeration systems and the development of smart management systems could be considered as a next step.

## Mobilizing public and private financing

A rapid increase in sustainable cooling investment is required to close the gaps in access to clean cooling. This applies to both active cooling equipment such as efficient and environmentally friendly air conditioners and refrigerators, as well as passive cooling solutions such as energy-efficient cold rooms, building design, and heat-resilient landscape architecture (SEforALL 2021).

Increased public funding is required for national and local programmatic solutions, such as the development of new MEPS and training courses for cooling equipment maintenance providers, improving installation and servicing practices, and facilitating the adoption of new technologies. Furthermore, public funds are required for anti-dumping campaigns to transform markets and avoid the burden of obsolete and inefficient cooling technologies (IEA and UNEP 2020).

For most countries cold chain solutions are primarily driven by the private sector, including both established companies and smaller start-ups. The right policy environment can assist businesses in adapting and adjusting their business models and offerings to better serve the needs of smallholder farmers and their communities, who may not have easy access to the cold chain solutions described

[5] Sustainable Energy for All (SEforALL) is an international organization that works in partnership with the United Nations.

in the cooling plan. It is also critical to ensure effective coordination to facilitate continuous and efficient cold chain operations (K-CEP 2019).

## Enhancing international cooperation

It is essential to enhance international cooperation through universal ratification and implementation of the Kigali Amendment and global initiatives for clean cooling, such as the Biarritz Pledge for Fast Action on Efficient Cooling (France 2019). Table 3 below lists several examples of existing international initiatives:

***Table 3. Examples of existing international initiatives.***

| |
|---|
| The Biarritz G7 Pledge for Fast Action on Efficient Cooling (Appendix B) |
| The Climate and Clean Air Coalition's programs on Efficient Cooling and HFCs |
| The Cool Coalition |
| The Kigali Efficiency Program and Principles for National Cooling Plans |
| The World bank's Efficient Clean Cooling Program |
| The European Partnership for Energy and the Environment's Count on Cooling |
| COP26 – UK Government support for cooling |
| UNEP's District Cooling Initiative |
| The University of Oxford's Future of Cooling Program |
| U4E model regulations |
| The Africa Centre of Excellence for Sustainable Cooling and Cold-Chain (ACES) |

Nonetheless, increased international cooperation is required to achieve more significant impact by broadening membership and better using limited resources. For example, the Kigali Amendment had been ratified by over 98 countries as of July 2020. However, the agreement has yet to be ratified by some other countries, such as China, India, Indonesia, Turkey, Saudi Arabia, the United States, Brazil, Russia, and Italy for example. To ensure synergy, the secretariat for a new voluntary platform could be housed in one of the existing programs or coalitions, such as the Cool Coalition, the IEA Energy Efficiency Hub, or the Climate and Clean Air Coalition. A voluntary cooling platform could help avoid duplication, increase synergies and increase effectiveness through enhanced cooperation. Furthermore, international cooperation for energy-efficient and sustainable cooling necessitates strengthened leadership that builds on existing initiatives, fosters synergies, and addresses the new cooling challenges posed by the COVID-19 pandemic (Saud 2020).

# Country differences

Global cooling needs are significant and expected to grow rapidly, especially in high-impact countries, including the 'Critical 9' of India, China, Indonesia, Pakistan, Bangladesh, Nigeria, Mozambique, Sudan, and Brazil (SEforALL 2021). The rapid growth of the middle class in those countries experiencing significant increases in household income and purchasing power, leads to annual cooling equipment sales projected to reach 460 million units by 2030, up from 336 million in 2018 (Griffin, C and et al 2019).

However, SEforALL's Chilling Prospects report also found that there are over 1 billion poor people in those countries who are vulnerable to health and economic risks from rising temperatures in the absence of adequate cooling, and an additional 2.2 billion lower-middle income people lacking access to clean and efficient cooling, who are driving growing demand for cooling solutions. Access to clean cooling solutions is essential for effective climate change adaptation, particularly for those areas and population groups most vulnerable to the effects of rising global temperatures.

In developing countries, efficient, affordable, and long-term cooling can help alleviate poverty, reduce food waste, improve health, and combat climate change. Reducing food waste through refrigeration and food cold chains could feed approximately 1 billion undernourished people (The World Bank 2019). There are opportunities for investment in those emerging markets to bring sustainable cooling solutions to market, as well as cost savings in commercial and industrial facilities by installing efficient cooling equipment.

In conclusion, improved policy actions can promote rapid HFC phase-down in parallel with cooling equipment energy efficiency improvements, thus critical in creating a conducive framework for clean cooling. To maximize the climate and development benefits of clean cooling, policymakers must work together and integrate cooling efficiency technologies into larger frameworks. Furthermore, mobilizing funds from the public and private sectors is critical to facilitating long-term financial flows; improving international cooperation is also critical to establishing a community of practice capable of leveraging knowledge and existing resources to form partnerships and encourage more ambitious global commitments.

## How do we design indicators to measure progress on the adoption of clean cooling?

Table 4 lists indicators that can be used to assess the level of uptake, efficiency, and impact of applying clean cooling technologies. It also lists associated factors such as increased productivity which impact the take up and application of cooling technologies.

***Table 4. Indicators to assess clean cooling.***

| Factor | Assessment area | Measurement | Assessment method |
|---|---|---|---|
| **Carbon reduction Reduction in GHG emissions** | Food loss/waste<br>Scope 1 emissions from refrigerant leakage (fugitive) and diesel for the transport refrigeration units (TRUs)<br>Scope 2 emissions from electrical power usage | $CO_{2e}$ reduction, $MtCO_{2e}$ reduced over sector or per ton product produced | Guidelines published by IPCCC are used to estimate reductions in GHG emissions https://www.ipcc-nggip.iges.or.jp/public/2006gl/ |
| **Energy** | Energy used for processing, chilling, storage, transportation<br>Use of solar or renewable energy | Reduction in energy use over time (e.g., per year)<br>Quantity of solar installed ($m^2$/year) | Guidelines published by IPCCC are used to estimate reductions in GHG emissions https://www.ipcc-nggip.iges.or.jp/public/2006gl/<br>Returns from solar panel manufacturers (use for SIC or similar for sales) |
| **Overall life cycle assessment (LCA)** | Overall environmental assessment of sectors | $CO_{2e}$ per kg of product for food sectors | Specific LCA software (may need development for area) |

| Factor | Assessment area | Measurement | Assessment method |
|---|---|---|---|
| **Use of water** | Water used in food processing | Water used (litres/day or litres/ton of product processed) | Water rates/billing, water metering at producers<br>On farm use of water: Cool Farm Tool Water (https://coolfarmtool.org/coolfarmtool/water/) |
| **Use of chemicals** | Chemicals used in food processing/horticulture | Chemical use over sector or per hectare of land farmed | Sales of chemicals (SIC or similar)<br>Pesticide application: Cool Farm Tool (https://coolfarmtool.org/coolfarmtool/greenhouse-gases/) |
| **Productivity** | Food produced (animal/horticulture productivity) | Harvested yield and marketable yield product weights (litres/day, tons/hectare, kill weight)<br>Growing area<br>Fertilizer applications: type and rate<br>Herd or flock size<br>Feed used | Cool Farm Tool (https://coolfarmtool.org/coolfarmtool/greenhouse-gases/) |
| **Food** | Quantity of food that enters cold chain | Tons of food chilled/frozen | Returns from food producers of chilled/frozen food leaving factories |
| **Welfare** | Animal welfare standards | Number of animals killed in registered abattoirs | Welfare officer returns, assessment of legal prosecutions, number of animals killed in official abattoirs |
| **Health** | Human and animal health | Assessment of improved health of human and animal population | Number of days of sickness, days in hospital, drug and medicine use for humans<br>Use of drugs and medicines supplied for farm animals |
| **Efficiency** | Productivity of farms, sectors of the food chain | Specific energy consumption (SEC) for an area (e.g., kWh/ton of food cooled, kWh/m$^3$ of food stored, fuel per ton-mile transported) | Cool Farm Tool (https://coolfarmtool.org/coolfarmtool/greenhouse-gases/) |
| **Financial** | Increased income to operators | Increased income per farm, cold chain operator | Tax assessment, company accounts and returns<br>Number of animals owned per farm, average size of farms, milk/horticulture |

| Factor | Assessment area | Measurement | Assessment method |
|---|---|---|---|
| | | Money lent to cold chain operators to finance new business | production per animal/hectare<br>Number/amount of loans supplied by banks, NGOs |
| **Systems installed** | Number of cooling/storage/refrigerated transport systems installed and operational | Number of systems (number)<br>Refrigeration capacity of systems installed (kW duty)<br>Number of operators involved in sector (farmers, end users, logistics operators) | Permits supplied, tax code classification sales (e.g., SIC code type assessment) |
| **Training** | Number of people trained (farmers, cold chain operators, end users in food quality/safety, operation of cold chains, operation of cooling facilities, management of cooling facilities) | Take up of coursed in the cold chain sector | Number of people attending courses per year |

# Check list

Table 5. Check list for clean cooling. below summarizes the outputs and results from the report summarized in this report.

***Table 5. Check list for clean cooling.***

| Title | Issues | Link to page in document | Y/N |
|---|---|---|---|
| **Before starting project** | | | |
| Benefits | Clear link to benefits | 5 | ☐ |
| Needs assessment | Clear assessment of local needs and capabilities.<br>Public health needs<br>Reduction on food loss/waste<br>Nutrition/health<br>Need for additional facilities for pharmaceuticals, home storage, integration into whole food chain<br>Use of facility – full utilization, seasonal (consider moveable facilities) | 5 | |
| Local engagement, especially from producers' groups or trade bodies | If not available, may need to develop | 5 | ☐ |
| Marketing | Potential need to 'market' cold chain, create a market | 5 | |

| | | | |
|---|---|---|---|
| Impact | Impact on local population, what are larger benefits: income, jobs, female empowerment/entrepreneurship, nutrition and health, general local environment, contribution to local and national economy, food security | 5 | |
| Infrastructure | Roads, availability and training of contractors/maintainers, power supply, energy integrity | 5 | ☐ |
| Land availability and ownership | Land ownership, small farm areas, lack of finances to purchase land | 5 | ☐ |
| Support mechanisms to encourage implementation | Agronomy, AI. Increase yields | 5 | ☐ |
| Technology | Assessment of technologies for local needs and skills<br>Selection of best technology for application<br>What are best environmental options? Use of low GWP refrigerants, use of RES<br>Remote monitoring, predictive maintenance<br>What is available, what needs to be developed/adapted, feasibility | 9 | ☐ |
| Integration | Thermal/physical integration opportunities, RES | 9 | ☐ |
| Business model/case to be applied | Assess for specific location and specific project | 19 | ☐ |
| Links to larger producers | Is there a clear route to market and links to further processing that will provide a market for goods? | 21 | |
| Availability of equipment/components | Refrigerants<br>Taxes/imports | 9 | ☐ |
| Training and skills | What is available, what is required? | 16 | |
| Political/regulatory issues | Drivers or issues preventing take up | 21 | ☐ |
| Specification | Clear specification of what is required and needs | 10 | ☐ |
| **During project** | | | |
| Management of installation | Need for experience project manager | 10 | ☐ |
| Training of operators | Specific training on installation | 16 | ☐ |
| Specific training for maintainers | Specific training on installation | 16 | ☐ |
| Business support and training | Training for farmers/operators | 16 | ☐ |
| Commissioning | Check does what specified | 10 | ☐ |
| Feedback of knowledge | How would we do it better next time? | 16 | ☐ |
| Support service development | Veterinary, crop services to support farmers, outreach to farmers | 5 | ☐ |
| **After project** | | | |
| Training and skills | Ongoing development | 16 | ☐ |

| | | | |
|---|---|---|---|
| Monitoring and maintenance | Ongoing monitoring of issues/success, ongoing performance/efficiency | 16 | ☐ |
| Demonstration | Demonstrating project to others | 16 | ☐ |
| 'Stories' | Benefits of 'seeing' success. Local 'champions' | 16 | ☐ |
| Case studies | Benefits of 'seeing' success | 16 | ☐ |
| Learning and feedback | What could be done better? | 25 | ☐ |
| Improvement | Make sure feedback is applied | 25 | ☐ |
| Regulation and policy for ongoing support. Licensing of premises | Ensure regulation is applied, monitor for needs for improved/new regulations. Check premises are licensed, and rules are being applied | 21 | ☐ |
| Support for development of larger producers | Provide support for producers who wish to expand. This can be technical, financial, business models, marketing, training | 19 | ☐ |
| Review and adjust | Ongoing annual basis | 25 | ☐ |
| Ongoing support | Provided regular monitoring of ongoing needs, continue learnings and feedback for continuous improvement | 25 | |

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