Towards a net-zero food cold-chain

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ABSTRACT

2020 was the year that the importance of the food cold-chain in society became more visible. Its key role in the continuous supply of food was highlighted during the Covid-19 lockdown and the Brexit transition. Globally, a lack of adequate cold-chains is responsible for about a quarter of food losses in emerging economies, impacting rural incomes and food security.

Both in the UK and globally, significant challenges exist for cold-chain operators to both ensure resilience and seamless operation, while enabling the sector to become net-zero carbon by 2050. In the UK, more than 60% of our food is dependent on the cold-chain, and with high direct and indirect emissions, food refrigeration alone is estimated to be responsible for up to 4% of the UK's total greenhouse gas (GHG) emissions.

Keywords: Cold-chain, Food, Zero Carbon.

1. INTRODUCTION

To achieve the UK's net-zero carbon emissions target by 2050 is challenging. Food security is an integrated global issue. The UK is reliant on imports; 84% of fruits and 47% of vegetables were imported in 2019 (DEFRA). Global food demand is set to grow by 50% by 2050, driven by people living in developing countries moving to cities and a shift to more western diets. Although this creates opportunities for UK farmers, fishers and food producers, it also increases energy use. At the same time global warming is impacting food production and deteriorating arable land and reducing water availability.

The food and drink industry is the largest manufacturing sector in the UK; it is responsible for 176 $MtCO_{2e}$ emissions (excluding, amongst other items, pre-farm production, packaging, food waste, land use change) (DEFRA, 2013). The sector (encompassing food production, manufacturing, distribution and retailing) is worth £120 bn and accounts for 9.4% of national gross value added (GVA). There are over 4 m jobs in the sector of which 3 m are in food retailing and catering. The environmental impact of the sector is huge, accounting for 190 million m^3 of water per year, 12 MT of food waste, 24% of anthropogenic carbon emission and 28% of UK road freight by tonnage. Food refrigeration is estimated to be responsible for 2-4% of the UK's total GHG emissions (Carbon Trust, 2020).

Food security requires cold-chains. In developed countries at least 33% of food is temperature-managed in the supply chain. Globally, only 15% of all food that would benefit from refrigeration is refrigerated. Approximately 30% of perishable food is lost in developing countries due to the absence of cold-chains. For example, it is estimated that of the 4 million metric tons of fruits and vegetables produced in India anually, that about 30-40% is wasted, resulting in loss of around USD 12.63 bn (RStv, 2016). In Rwanda, inadequate post-harvest handling results in 40% of food being lost (ministry of Environment, 2019). This equates to 21% of its total land use, 16% of its greenhouse gas emissions, and a 12% loss to its annual GDP (World Bank. 2020). The production of food which does not make it to market accounts for ~2 GT CO_{2e} per annum (a further ~2.4 GT is from food waste) (UNEP, 2019); it also impacts waste of natural resources including land and water.

Conventional cold-chains for food are energy intensive and use refrigerants (which often have high global warming potentials). Cooling sectors account for 86% of the GWP impact of HFCs. Supermarket refrigeration accounts for 3% of UK electricity consumption. Twenty percent of the energy consumption of a temperature controlled logistics vehicle is for refrigeration.

Availability of market information varies across the food cold-chain, with some sectors providing little information. For example, Chilled Food Association (CFA, 2021) states: 'There is no official collection of market data either in the UK, EU or internationally' (for chilled foods). One of the challenges to reach net-zero carbon emissions is to be able to quantify and document carbon usage and reductions. Evidence from sources such as climate change levy (CCL) data shows that sectors such as cold storage and retail have reduced carbon emissions over the last 5-10 years and so it is essential when benchmarking the cold-chain that up to date information is used in the assessment.

The food industry is highly complex and fragmented. Sectors are often segmented and data sharing and collaboration between sectors is rare. There is no real interconnectivity between sectors which limits opportunities for sectors to work together to optimise the overall food chain. The Covid-19 pandemic had a major impact on the food cold-chain in the UK with food shortages and the inability for producers and retailers to get food to consumers. It identified the vulnerability of the food cold-chain but also forced retailers to work more closely together to supply food to their customers. Greater connectivity and integration are opportunities to reduce carbon emissions and food waste whilst also creating new business models. Cold-chains that are more data driven could have significant advantages. The IIR (2020) state that a more digitally driven cold-chain could potentially lower procurement costs by 20%, reduce supply chain process costs by 50% and increase revenues by 10%. It could also reduce food loss and waste and carbon emissions.

Cold-chains include both static and mobile elements which have to work seamlessly together. Traditional approaches to intervention have been mainly reductionist with piecemeal projects testing individual cold-chain technologies or interventions in silos (cold storage, supermarket chiller cabinets, and transport refrigeration). Optimising the sub-systems neglects the interdependencies between them (and their relationship with other 'local' energy vectors) – and results in a sub-optimal system. An integrated transition to energy-efficient technology and economically optimised, net-zero cold-chains is unlikely to emerge organically given the many actors both in the UK and in global supply chains; this can risk the UK's climate targets, energy security and food security as well as risk economic opportunity for our food growers, fishers and producers.

2. ZERO CARBON STRATEGIES

A strategy to reach net-zero carbon is complex but involves first benchmarking the existing cold-chain and defining the assessment envelope. Then strategies to reduce, shift, improve and aggregate can be applied (not necessarily in order) across the value chain of the cold-chain system (using, making, storing, moving and managing cold) (Figure 1). These encompass:

1) Reduce: Reducing the need for cooling, whilst ensuring optimal conditions for food in the UK supply chain;

2) Shift: Transitioning to more sustainable technologies and working fluids and taking different approaches to cooling as well as novel energy sources including free, thermal to thermal, waste heat and cold;

3) Improve: Enhance equipment and operational efficiency; and

4) Aggregate: Identify and exploit synergies within the cold-chain to better integrate different cooling demands into a single system and enhance thermal symbiosis of cooling systems with heating and other available energy vectors.

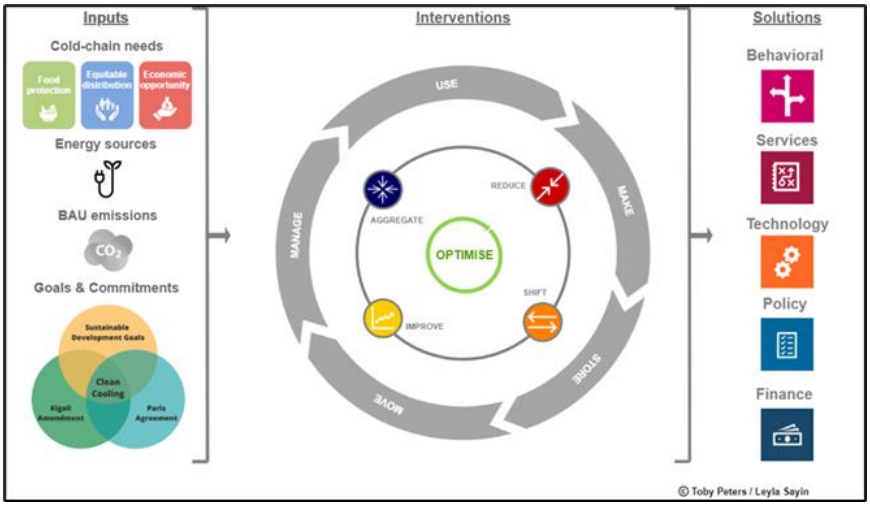

Figure 1. Zero-Emission Cold-chain Overall Structure

2.1. Benchmarking

Providing an accurate baseline to quantify progress against is challenging. Taking the UK as a territory is the usual approach by Government. However, saving carbon within a territory can be achieved by moving manufacturing offshore or closing the most polluting factories within a territory. The question then arises whether the production that is moved offshore uses more or less carbon than it did in the UK? If the former, nothing has been saved and the situation has actually been exacerbated. Creating an envelope around the UK only impacts on production and not consumption. The UK's Committee for Climate Change (CCC, 2020) report shows that carbon consumption is 70% higher than carbon production (at ~800 $MtCO_{2e}$/year for consumption emissions and ~470 $MtCO_{2e}$/year for UK consumption emissions). Past figures indicate that approximately one fifth of direct UK food chain emissions occur outside the UK (Audesley, 2009). However, this covers the whole chain from farm to fork.

Even though these figures are estimates, it shows the difference between the carbon emissions that originate in UK territory and the total carbon emissions for the UK (Figure 2). It should be noted that the UK's zero carbon emissions target is for net UK carbon production and not net-zero carbon consumption which is much more challenging.

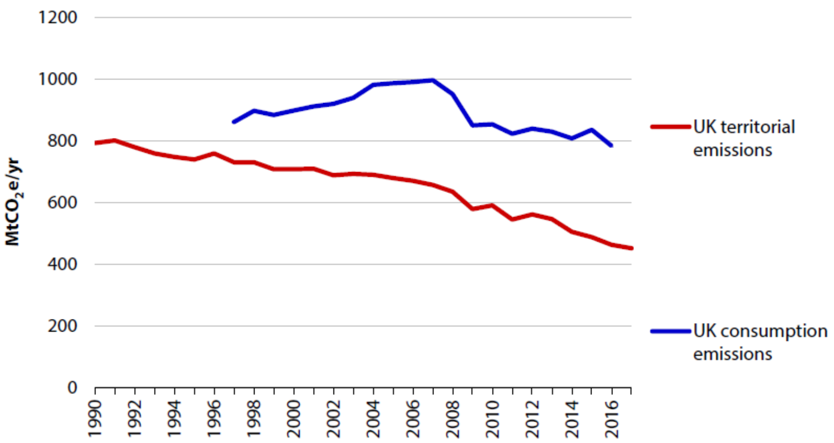

Figure 2. Emissions in the UK (taken from Committee for Climate Change (CCC), 2019)

Pragmatically we have to work on what we can control, but also encourage and help other nations to become net-zero carbon and place more emphasis and make information available (particularly to consumers) on the emissions associated with imports. Whether this is though carbon labelling, regulation, carbon taxes or better information for consumers (or a combination of these) is an ongoing debate. Much of the current Government thinking seems to be to prioritise reduction in food waste and to provide consumers with greater information on labels so that food is stored better and there is greater knowledge of the environmental impact of food items (CCC, 2019).

2.2. Emissions from food worldwide

Worldwide food accounts for approximately 26% of GHG emissions (Poore and Nemecek, 2018). Of this, 18% (4.7% of the total) of the emissions are related to the supply chain (food processing at 4%, transport at 6%, packaging at 5% and retail at 3%) (Figure 3). This excludes domestic food related emissions which result from food refrigeration and food waste (which in developed countries is often 30% of food purchased and equivalent to 3.3 billion tonnes of $CO2_{eq}$). These figures are for all food processes and refrigeration is a part of these figures. There is quite limited data on the impact of refrigeration, but it is estimated to be approximately 1% of total CO_{2e} emissions (Carbon Trust 2020).

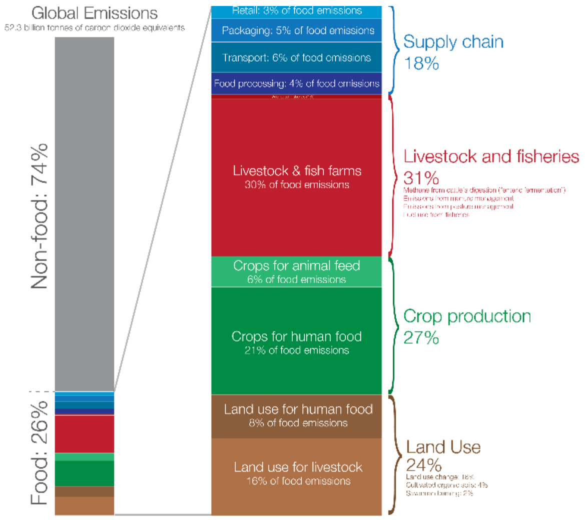

Figure 3. Global GHG emissions from food production (adapted from Poore and Nemecek, 2018 by Our World in Data)

2.3. UK emissions from food

The total UK electricity demand in 2019 was estimated by DUKES (2020) to be 346 TWh. The food industry accounts for 13% of UK industrial electricity demand (3.5% of total). This excludes energy used for food in domestic and commercial premises which is not quantified (Figure 4). According to DUKES (2015) emissions from energy in the food and drink manufacturing sector fell by 42% between 1990 and 2015. At the same time the industry grew by 20% and so this indicates that significant decarbonisation has already occurred (Food and Drink. 2017). The impact that refrigeration has is quite poorly quantified. Estimates are that refrigeration counts for 2-4% of the UK's GHG emissions (Carbon Trust, 2020). As part of a new project funded by UKERC the authors are due to collect better quantified information on the impact that the cold-chain has on UK emissions.

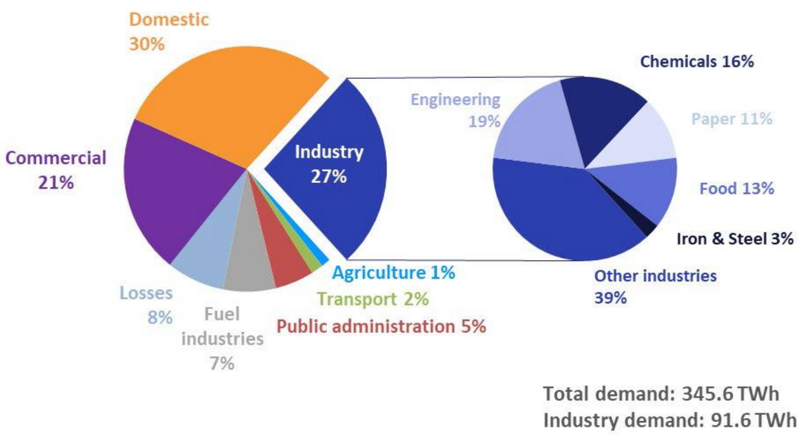

Figure 4. Electricity demand by sector in 2019 (DUKES, 2020)

Carbon emissions in the food cold-chain generally originate from direct (refrigerant leakage) or indirect effects. Indirect emissions are mainly from electricity in the UK cold-chain post-harvest/slaughter (Audsley et al 2009). Therefore the focus should be on reducing emissions of high GWP refrigerant or transitioning to low GWP alternatives and reducing usage of electricity (through better efficiency).

2.4. Reduce

Reducing carbon emissions is often thought of as a technical issue. Technologies do play an important part, but behaviour, policy and business drivers are also involved. A good example of a technology that would have a huge carbon reduction benefit is to fit doors to open fronted retail display cabinets. Work by Foster et al (2018) examined the carbon saving opportunities for a typical UK supermarket (Figure 5). For cabinets currently installed in a supermarket the largest carbon savings could be achieved through retrofitting strip curtains or the addition of doors on open fronted cabinets. Further benefits could be achieved if the best thermally performing doors were applied to both medium temperature (MT) and low temperature (LT) cabinets. In all cases the technology could be applied relatively rapidly (<1 year) and paybacks of 1-2.5 years were achievable which would be acceptable to a supermarket. It would seem that either the use of strip curtains or doors would be obvious opportunities to not only save carbon but also use less energy and save money. However, both technologies create a barrier between the food and the customer. The use of strip curtains in a large supermarket may reasonable be discounted as the curtains do become damaged and dirty and the energy and carbon saving benefits are less clear. Fitting doors to open fronted cabinets also results in some issues such as ensuring doors are not left open, maintaining the doors in good operational condition, adjusting the operation of the refrigeration plant to cope with the reduced load and keeping the doors clean. However, the greatest barrier to application is the perception that the doors will reduce food purchased by consumers. Limited information is available to justify whether this is correct. One of the best studies is from New Zealand (Robertson, 2015) where doors were installed on cabinets in 2 stores. Energy savings of 42% were achieved and customers perceived the shopping aisles as being more comfortable (less cold). Sales of staple items were unchanged in the trials over a 12 week period. Initially sales of non-stable items reduced (they were already declining at the start of the trial) but then began to return to the original levels. However, the supermarket made a decision to remove the doors at the point they saw reductions in sales and so the trial was not continued to full completion. Even though there were strong arguments in terms of energy, carbon and customer comfort to retain the doors the supermarket prioritised product sales above everything else. As long as supermarkets perceive there is an issue with product sales it seems unlikely that doors will universally be applied in larger supermarkets (smaller stores have seen a growth in the use of doors as these stores focus less on impulse food sales) voluntarily. Other drivers may encourage supermarkets to fit doors. Eco-design and energy labelling (applied from 1 March 2021) for supermarket cabinets are only applied to new cabinets and so will have little impact on currently installed cabinets. However, energy labels may be a means to better identify the energy savings from closed door cabinets and certainly supermarkets will be incentivised to purchase the better performing level cabinets. Alternatively Government can legislate (as has been applied in the Netherlands (Amsterdamer, 2007) and Switzerland (Anwendungshilfe Minergie, 2007)) or industry can reach voluntary agreements or codes of conduct, such as has been done in France. In France the French Retailers Association (FCD) agreed a code of conduct that doors would be installed on all cabinets in new and refurbished stores (signatories included: Auchan, Carrefour, Casino, Cora, Francap and Monoprix).

To decarbonise cooling the food industry will need to reduce direct and indirect emissions. However, it is not possible by either reducing direct emissions from refrigerant loss or applying the best energy efficient options that zero carbon can be achieved. The carbon emissions gap between what can be achieved by reducing emissions can be mitigated by sequestration or by purchasing or generating renewable energy. This could potentially make the food chain zero carbon. However, as industry and the whole UK becomes more reliant on renewable energy there will be a greater need to align generation and use of energy. This will mean that industry will have to adopt new approaches to how they manage the cold-chain.

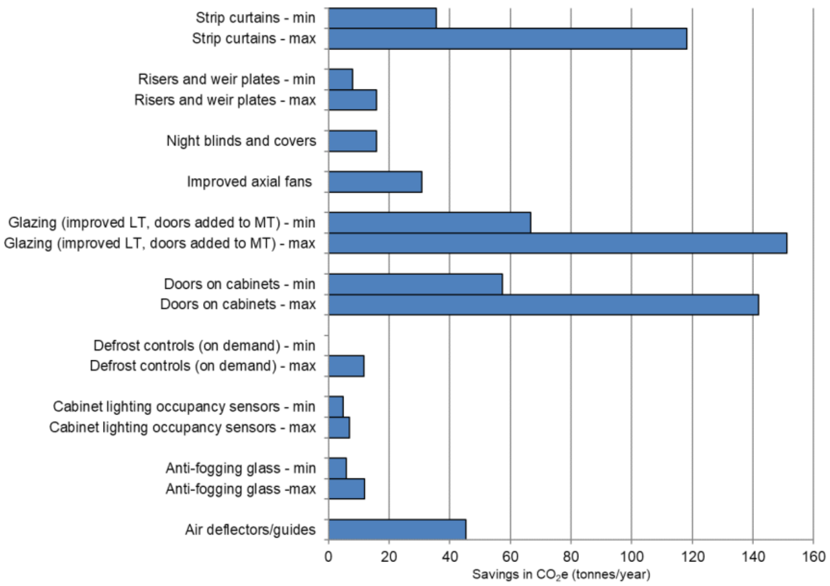

Figure 5. Retrofit carbon saving opportunities in a typical UK supermarket (Foster et al. 2018)

2.5. Shift

To reach net-zero carbon there will need to be not only a transition to low GWP refrigerants and low energy technologies but also enhanced integration between users and the grid. This is likely to mean greater use of methods to store energy (electrical, thermal, mechanical, chemical). A large selection of energy storage mechanisms exists or are being developed (Figure 6). These have very different storage capacities and rated powers and so are suited to different modes of operation, locations and applications. It seems unlikely that one energy storage technology will dominate entirely.

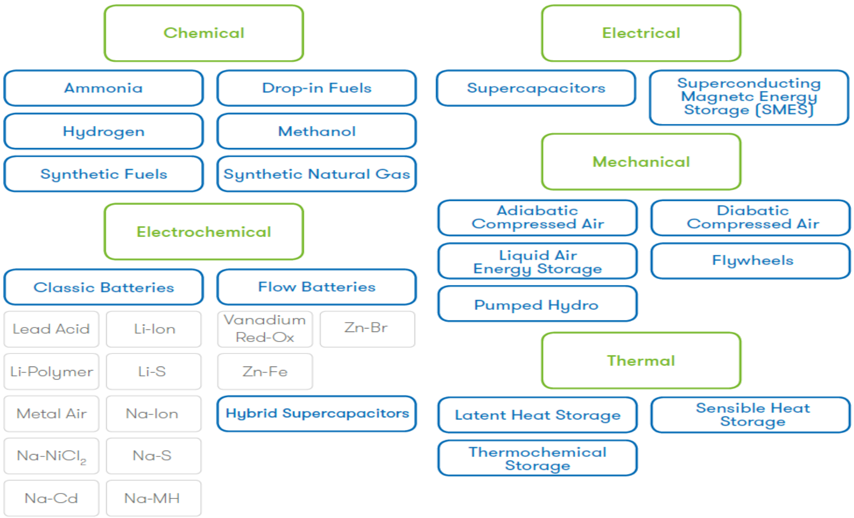

Figure 6. Energy storage technologies

Food itself can also be used as a thermal 'battery'. Cold stores already 'load shift' by switching off their refrigeration systems at peak grid demand to save on the high energy tariffs at these times. This currently provides the cold store with a monetary saving as they consume energy at a lower tariff rate but also it provides a benefit to the grid. At peak grid demand times higher carbon emitting power generation systems need to be bought into action. If use of these high carbon emitting power generators can be removed or reduced the carbon emitted from the grid is reduced.

Demand side response (DSR) is likely to have a greater place in the future energy grid. Work has already been carried out to remove supermarkets from the grid at peak grid demand times and it has been shown that chilled cabinets can be turned off for periods similar to those of the routinely applied defrost periods. For chilled foods the DSR period is restricted, as the food temperature prior to the DSR period cannot be reduced too low without freezing the food. In addition food temperature cannot be allowed to rise too high or food safety and quality may be compromised. It is far simpler to use frozen food as a thermal battery as it is possible to reduce the food temperature before the DSR period and then allow the food temperature to increase whilst the DRS period is in operation.

In the future it is likely that the food chain will need to be better integrated into the UK grid. To incentivise industry to do this there will probably be a need for variable tariffs that reflect the position that the grid is in at that particular time. For example the more structured tariff system that is currently in place is likely to be replaced by one more similar to the Octopus energy model where tariffs continually change in relation to the energy available on the grid (Octopus energy, 2021). This will also mean that industry will need to be able to react quickly to fluctuations in the grid and act accordingly and will be rewarded financially.

2.6. Improve

New technologies will play a role in decarbonisation. However, the UK's target to become net-zero carbon by 2050 only gives the industry 30 years to apply new technologies. For many sectors such as manufacturing and cold storage where the replacement rate of facilities may only be every 20-30 years this gives little opportunity for rapid application of new technologies and so reducing and shifting carbon may be the only available opportunities. In other sectors of the food chain such as transport, retail, professional catering and the home there is a far higher replacement rate. For example supermarkets replace display cabinets at approximately 7-8 year intervals and consumers replace domestic refrigerators approximately every 10 years. This provides greater opportunities for completely new technologies to be applied.

For the second of these examples, a recently published study by Choi et al (2021) has indicated that even though the performance of domestic refrigerators has improved dramatically since energy labelling was introduced in the early 1990s there are still significant opportunities for improvement. In the study they found that carbon emissions could be reduced by up to 14.7% using new refrigeration cycles and by up to 10% by applying different manufacturing materials. The authors pointed out that currently the majority of carbon is still embedded in the usage phase (90%) but that as energy efficiency improves a greater proportion of carbon will be associated with manufacturing and end of life. Therefore in future a life cycle climate performance (LCCP) approach will be more relevant.

2.7. Aggregate

To achieve carbon reduction targets probably more is required than applying the best and most efficient technologies and integrating better with the grid. Considerable wasted resources exist that are currently not utilised. Companies such as Danfoss are already developing smart energy systems for supermarkets where the supermarket not only supplies all its required heating and cooling but also contributes to district heating and cooling networks. Danfoss claim that CO_2 savings of 60 – 70% can be achieved if all options are applied (Funder-Kristensen, 2018)).

New business models such as servitisation (for example cooling as a service) may also contribute to aggregation as an overall system operator will be responsible for multiple operations. Through this they would be able to utilise all available energy vectors more efficiently and effectively. Such models are beginning to be applied, especially in developing countries where the initial investment for cooling systems prohibits entry into the market for many users. For example, the concept of 'Community Cooling Hubs'[1] (CCH) are to be trialled in India as part of a collaboration amongst Centre for Environment Education (CEE), MP Ensystems, with support from Shakti Sustainable Energy Foundation (SSEF) and the University of Birmingham. By aggregating cooling and heating demand to optimize system efficient energy and resource management and bundle multiple revenues streams, and by incorporating passive solutions and

[1] The concept and underlying socio-techno-economic design of 'Community Cooling Hubs' has been developed by Professor Toby Peters of University of Birmingham, and Prof Pawanexh Kohli, Former Director, National Centre for Cold-chain Development (NCCD), Government of India.

renewable energy (RE) technologies, CCH can facilitate a cohesive approach focused on meeting a portfolio of a rural community's societal needs with economic accessibility and resilience.

2.8. Developing countries

The demand for cooling will expand dramatically as access to cooling increases in developing and newly industrialised countries. The needs for cooling and storage facilities and refrigerated transport are increasing rapidly. For example the carbon emissions from cold stores, pack houses, reefer vehicles and reopening chambers in India are anticipated to grow by 136% between 2017 and 2027 (Carbon Trust 2020). This means that even if we in the UK can reach our net-zero carbon emissions targets other countries are rapidly increasing their carbon emissions.

Key barriers faced for successfully implementing new low carbon cooling technologies in developing nations include lack of skills and training, limited or unreliable energy access, and lack of financing and sustainable business models. An insufficient supply of engineers, technicians and mechanics with the relevant skill set to install, operate, maintain and decommission the new technologies, along with inadequate training to develop such skills, would slow uptake and potentially lead to poorly optimised and performing cold-chains. In turm this results in unnecessary energy use, GHG emissions, environmental pollution and damage. Moreover, rural regions in many developing countries often struggle with unreliable, severely constrained or non-existent power grids. For example, in 2018, only 23% of the rural population in Rwanda has access to electricity compared to 89% in urban areas. Such regions would benefit significantly from sustainable off-grid efficient cooling technologies as an alternative to the current default option of adopting expensive to run diesel-fuelled generators. Furthermore, the higher upfront capital investment cost typically associated with the new technologies, when compared to procuring conventional options, often acts as a major barrier to making the switch to such systems. Underpinning the relatively high retail price is the current low level of volume demand for sustainable cooling technologies, which is partly due to a lack of awareness of the need for their adoption and an absence of procurement and financing approaches, and business models .

Therefore, there is a need to share knowledge and resources to ensure that these emerging nations apply the best low carbon technologies. As an example, The African Centre of Excellence for Sustainable Cooling and Cold Chain (ACES) was launched in 2020 as a collaboration of the Governments of Rwanda and the United Kingdom, UNEP's United for Efficiency (U4E) initiative, University of Birmingham and the Centre for Sustainable Cooling, and a range of academic institutions. The mission of ACES is to develop and accelerate uptake of sustainable, system-driven cooling and cold-chain solutions in both agriculture and health sectors to economically empower farmers, increase export revenues, enhance job creation in rural areas, mitigate climate and environment impacts, and foster low-carbon development. Through ACES, the collaboration brings together the multi-disciplinary international and in-country expertise necessary to develop, demonstrate and provide the technical assistance for implementing the step-change pathways (culture and social, technology, manufacturing, skills, policy, business models, financing) for achieving: (i) affordable (whole of life), (ii) greatest energy system resilience, and (iii) lowest carbon emissions while (iv) meeting social and economic cold-chain, post harverst management and rural cooling needs.

3. CONCLUSIONS

Significant challenges exist to not only reduce emissions from the UK cold-chain but also to reduce the impact of 'imported' carbon emissions from other countries. Developing nations are increasingly seeing the need for cooling to reduce food loss and enhance food quality and safety. Emissions from cooling will therefore increase in these countries and we risk sub-optimal technologies and high GWP refrigerants being applied. There is a pressing need to avoid applying technologies that will later need expensive and sub optimal retrofitting to improve performance.

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