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Baseline Refrigeration Emissions in the UK

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ABSTRACT

Food cold chains are energy intensive and use high global warming refrigerants. The aim of this work was to benchmark the existing UK cold chain and provide robust evidence-based data on emissions in 2020. Only emissions from refrigeration within UK borders was considered, both from refrigerant leakage and from electrical power usage. Refrigeration in the food cold chain accounted for approximately 28.6 TWh/a of electrical energy consumption. Emissions caused by the generation of the electrical power, plus the emissions from road transport vehicles attributed to the TRUs were between 6.9 and 7.9 $MtCO_{2e}$. Emissions from the refrigerants within the refrigerated equipment were 5.4 $MtCO_{2e}$. It is clear from the results that energy consumption of domestic refrigeration and refrigerant emissions from retail refrigeration are the sectors which require the greatest focus.

Key words: Emissions, Cold Chain, Global Warming

1 INTRODUCTION

The food and drink industry is the largest manufacturing sector in the UK. The agri-food sector was worth £120 bn and accounted for 9.4% of national gross value added (GVA) in 2018. The agri-food sector employs 4.1 m people (DEFRA, 2020).

Conventional cold chains for food are energy intensive and use refrigerants, which often have high global warming potentials (GWPs). The leakage of these refrigerants to the atmosphere and the associated CO_{2e} emissions from the electricity used to power the refrigeration systems is significant. The food cold chain alone is responsible for a third of hydrofluorocarbon (HFC) emissions, or 1% of global greenhouse gas (GHG) emissions and food refrigeration is estimated to be responsible for 2-4% of the UKs total GHG emissions (Ravishanka et al 2020).

Availability of information varies across the food cold chain, with some sectors providing little information. For example, Chilled Food Association (CFA) state on their web site: ‘There is no official collection of market data either in the UK, EU or internationally’. 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 aim of this work was to benchmark the existing UK cold chain (chilled and frozen) and provide robust evidence-based data on emissions covering the periods 2019 to2020. Only emissions from the refrigeration were considered, both direct from refrigerant leakage and indirect from electrical power usage.

2 METHOD

The cold chain was split into sectors. These were:

- Agriculture
- Food and drink production
- Cold storage (after production)
- Retail

- Food service
- Transport between all sectors
- Domestic

GHG emissions were split into direct emissions from refrigerants and indirect emissions from the electricity consumed. As emissions from refrigerated transport units (TRUs) originate from the diesel engines that power the TRUs, these have been included in the energy consumption section, to separate them from the emissions from the refrigerants. For all sectors except transport the indirect emissions from energy consumption were converted into GHG emissions based on the carbon intensity of the grid in 2019 of 0.22 $kgCO_{2e}/kWh$ (BEIS, 2021). For transport, electricity is rarely used for the refrigeration, as refrigeration systems on vehicles are almost always driven directly from fossil fuels. Only the emissions associated with the refrigeration of the vehicle were considered and emissions to drive the vehicle were excluded.

A literature review of reports and peer reviewed papers was conducted with the aim of finding the latest and most comprehensive data on emissions. A level of confidence was attached to the results which considered the quality of data, agreement between separate sources and age of the data.

2.1 Energy consumption

For energy consumption the Digest of UK Energy Statistics (DUKES) was widely used. This data is compiled by the Department for Business, Energy & Industrial Strategy (BEIS) and contains data for many years up until the current year. The United Kingdom Statistics Authority has designated these statistics as National Statistics, in accordance with the Statistics and Registration Service Act 2007 and therefore they were considered as the most accurate data available. DUKES data does not always differentiate the energy consumed by refrigeration systems in each of the cold chain sectors and therefore further analysis and assumptions were often required. Energy consumption values shown were collated per year for the years 2019/2020, unless otherwise stated.

2.2 Emissions from refrigerant leakage

The main GHG refrigerants are the fluorinated gases (f-gases); hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs).

According to Brown et al (Brown et al., 2021) emissions of f-gases can occur at various stages of the refrigeration equipment life-cycle:

- During manufacturing
- During installation
- Over the operational lifetime
- At disposal.

The most comprehensive source of information for direct emissions is the UK Greenhouse Gas Inventory. This contains national greenhouse gas emission estimates for the period 1990-2019 and is the United Kingdom's National Inventory Report (NIR) submitted to the United Nations Framework Convention on Climate Change (UNFCCC). It includes losses during manufacture/initial charging and at decommissioning as well as losses in use.

3 RESULTS

3.1 Energy consumption

3.1.1 Agriculture and fisheries

During 2011, the UK farming and fishing sector accounted for 55.1 $MtCO_{2e}$ GHG emissions (DEFRA 2014). Enteric fermentation in ruminating animals and oxidisation of nitrogen in fertilisers were the sources of most of these emissions.

Dairying accounts for 57%, potatoes 23%, horticultural field crops 10%, protected crops 5% and poultry 5% of the refrigeration energy (Warwick et al., 2007). The main use of refrigeration and cooling in dairy is the rapid removal of "body heat" from milk, whilst in the case of field vegetables it is the removal of "field heat" after harvest. Refrigeration and cooling are also used during the storage of crops.

According to DUKES data for 2019 (BEIS 2020), agriculture (including tobacco and fisheries) used 1.51 Mtoe (17.50 TWh) of final energy, of which 362 ktoe (4.21 TWh) was electrical consumption. DUKES does not break the consumption down to the level of refrigeration.

Warwick et al. (2007) calculated that in 2005, 1.15 TWh (6%) of energy use in agriculture was for refrigeration. This energy consumption presented was primary energy consumption (energy of primary energy source, e.g. power station) and was based on CCL returns. Therefore, the final energy consumption (energy consumption at appliance) would be 2.6 times less (primary energy factor at the time) which equals 0.44 TWh (2.3% of the total energy consumption).

If we assume that 2.3% of the energy consumption in 2019 was refrigeration and compare this to the DUKES energy consumption for 2019 (17.50 TWh) this provides a refrigeration energy consumption of 0.40 TWh. This is 9% less than the refrigeration energy consumption presented by (Warwick et al., 2007) in 2005.

SKM Enviros (2011) carried out a study into GHG emissions from refrigeration systems in the UK food chain in the period October 2010 to May 2011. They estimated energy consumption of 0.44 TWh for refrigeration which was 11% of total energy consumption for the sector. This exactly matches the value from Warwick et al. (2007).

The sources above provide good consensus on an energy consumption for the sector of between 0.40 and 0.44 TWh with a high confidence.

3.1.2 Food and drink manufacture

Much of the refrigeration energy in this sector is used to extract heat from products to chill or freeze them. Once heat is extracted from the food, the refrigeration system energy is much less as there is only a requirement to maintain the food at the correct temperature in a holding room.

During 2011, the food manufacturing sector accounted for 13 $MtCO_{2e}$ of GHG emissions and 5.2 Mtoe (60 TWh) of primary energy was used (DEFRA 2014). Natural gas accounted for 62% and electricity 30% of total energy consumption in food and drink manufacturing in 2011.

DUKES data for 2019 (BEIS 2020) shows the manufacture of food products used 214 ktoe (2.49 TWh) of refrigeration and beverages used 51 ktoe (0.59 TWh) of final energy giving a total of 3.08 TWh.

As the source comes from government statistics and requires no further adjustment, it is considered as a high confidence.

3.1.3 Cold storage

The cold storage sector was considered separately from cold storage rooms. Cold storage rooms are used in food manufacture, retail and food service, however, the emissions from these usually relatively small rooms are considered in those specific sectors. The cold storage sector was considered as cold storage facilities not within these other sectors, however, some double accounting cannot be avoided. Most of these systems are large industrial systems. The refrigeration system is only required to maintain the product at low temperature, although at some cold store sites there are associated blast freezer facilities.

In 2018, the 425 cold stores registered under the Cold Chain Federation's (CCFs) climate change agreement (CCA) used 3.5 TWh of primary energy (CCF 2020). The final electrical energy consumption was therefore 1.35 TWh, using the conversion factor used by CCF.

Based on CCAs in 2017 and 2018 (Environment Agency, 2019), the 238 cold storage organisations (some organisations have more than 1 store) who submitted a CCA, had total emissions of 1.37 $MtCO_{2e}$ over the 2 years, or an average of 0.685 $MtCO_{2e}$ per year. This does not include direct emissions from refrigerant leakage and is derived from a specific calculation from electrical consumption that does not take into account renewables in the grid. An energy consumption of 1.32 TWh was calculated using CCA equations and current electrical carbon intensity of the grid. This is 2% less than that reported by (CCF 2020, 1-17).

As not all cold storage organisations will be part of a CCA, there may be more emissions from these organisations than reported via the CCL. Fikiin et al. (2017) used databases and Google maps and found facilities with a total of 39.4 million m^3 cold storage space in the UK. This was calculated from 253 cold store facilities with a floor area of 3.65 million m^2. As the number and total size of stores is lower than those reported by (CCF, 2020) and (CCF, SCR 2020) it seems reasonable to assume that the CCAs cover the vast majority of store energy consumption.

SKM Enviros (2011) estimated 0.9 TWh of electrical consumption for cold storage and 80% of this (0.68 TWh) was directly for refrigeration. As this data was based on 200 questionnaires and was 10 years old, it was not given the confidence of the previous data.

An energy consumption of 1.32 TWh was chosen and considered of high confidence.

3.1.4 Retail

During 2011 it was estimated that food retail accounted for 4.9 Mtoe of primary energy (56.7 TWh), therefore 19.4 TWh of final energy consumption (based on primary/final energy ratio in 2011 of 2.93 (DEFRA, 2014). In this sector refrigeration in supermarkets is typically from large distributed systems serving many retail display cases. In small shops there is widespread use of integral systems and small split systems (with a remote condensing unit serving one or more display cases).

The cooling demands in retail are a “holding load” – the aim is that product is received at the correct temperature and must be kept at that temperature in bulk storage or in retail display cabinets. SKM Enviros (2011) estimated that during 2010 retail stores consumed 27.3 TWh of electricity of which 27% (7.36 TWh) was used in refrigeration. The total electrical consumption was 25% higher than the final energy consumption from DEFRA (2014) which would have also included gas, used mainly for heating, meaning the SKM Enviros energy consumption was more than 25% higher than that from DEFRA.

BEIS (2016) modelled data based on telephone survey responses for the period 2014/15 and showed that the retail sector consumed 21.7 TWh of electrical energy. For large retails chains (100+ outlets) the proportion of refrigeration to electrical energy consumption was 42.3%. Cooled storage in the retail sector was shown to be 6.96 TWh, including cooling in large food shops with floor area exceeding 750 m^2 (3.27 TWh) and small shops (3.63 TWh),

These two reported figures from 2011 and 2014/15 were reasonably close at 6.96 and 7.36 TWh. No more recent published data could be found so this was considered as medium confidence.

3.1.5 Food service

The food service sector is made up of many sub sectors, e.g. restaurants (eat in and take-away), pubs and clubs, cafés, hotels, leisure, staff canteens, health care and education. Food and drink is mainly refrigerated in small systems including integral systems (e.g. drinks coolers, food display cases) and small split systems (e.g. cellar cooling in pubs and small walk-in cold stores).

(SKM Enviros (2011) estimated for 2010 that 14.8 TWh of electrical consumption was used in food service, of which 4.16 TWh was for refrigeration (28%).

Electricity consumption data collected by Mudie et al. (2016) in a sample of fourteen UK public house-restaurants (gastro pubs) showed that refrigeration represented the largest consumption in each of the study kitchens, using 41% of the electricity (13% walk in freezer, 5% walk in fridge and 23% other refrigeration). This was 28% of the total energy (including gas) of the kitchen, with the kitchen using 63% of the whole business area.

Kemna et al. (2021) stated that there were 9.14 million professional refrigeration products (storage cabinets, process chillers and condensing units) in stock in the EU (assumed EU 28, including UK) in 2020. The energy consumption of equipment used in this sector for 2020 was 9 TWh for storage cabinets and 28

TWh for condensing units. However, condensing units are also likely to be used in other sectors such as retail. The UK had 14.2% of the population of the EU, therefore if we pro rata based on population the energy consumption is 1.28 TWh per year for storage cabinets.

According to modelled data based on telephone survey responses for the period 2014/15, the hospitality sector consumed 8.76 TWh of electrical energy (BEIS, 2016). Hospitality was defined as cafes, hotels, pubs, restaurants and takeaways. It did not include hospitality premises that were present in other building types and therefore underestimated the number of sites (97,100 as opposed to 257,000 according to SKM Enviros (2014). The largest sub sector for cooled storage was pubs which accounted for 70% (BEIS, 2016). Cooled storage accounted for 1.35 TWh of energy consumption (15%). This value is 5% higher than storage cabinets reported in Kemna et al (Kemna et al., 2021).

According to a study by (SKM Enviros, 2014) there were 1 $MtCO_{2e}$ emissions from beverage refrigeration in food service. Based on the electricity emission factor given this means that 1 TWh was consumed. It was reported that 80% of the emissions in food service and retail are from bottle coolers.

Data from a database provided by the Food Equipment Association (FEA) was used to estimate the energy consumed by all the refrigeration equipment in the UK's food service industry. This database contains up to date data on number of facilities and estimates the number of items of refrigerated equipment in each facility. The database showed an average of 19.2 refrigerated appliances per site. This was much larger than the 5.8 refrigerated appliances per site provided by (ICF, 2011). Using European stock data for appliances from (Kemna et al., 2021) and (EC 2015) and correcting based on population and energy consumptions for appliance from a number of sources (SKM Enviros, 2014), (Mudie et al., 2016), (Fisher et al., 2012), (Pentland 2021) emissions of 7.89 TWh were calculated. Conversations are still ongoing with the FEA to try and establish a more accurate estimation.

There is a wide range of emissions values reported which reflects the disparate nature of food service. The emissions were considered to be between 4.16 and 7.89 TWh. A medium confidence that the emissions fall within these values was used.

3.1.6 Transport refrigeration

This sector is split into land and marine refrigeration. It only considers domestic transport and therefore does not include transport outside of the UK border.

Road transport

In this sector the refrigeration systems can be powered directly from the vehicle's main engine, or from a separate diesel-powered auxiliary TRU. TRUs are categorised in policy as Non-Road Mobile Machinery (NRMM), which means they have not been subject to the same regulation, or research into emissions and are also not included in emission estimates for the transport sector (CCF, 2021).

According to CCF (2021) there is a lack of data, e.g. number of temperature controlled vehicles on the road and the emissions from these vehicles. Although these vehicles are registered, there is no specific classification for temperature-controlled vehicles and a significant number on UK roads are not registered or operated by UK companies.

According to (McGinlay 2004) there were 47,500 refrigeration units on HGVs with an average power rating of 11.5 kW and an annual usage of 2500 hours per year. Fuel consumption is typically 3 l/hour when the unit is at full capacity (100% compressor run time). Based on carbon intensity of diesel fuel of 2.63 kg of CO_{2e} per litre this gives 0.7 $MtCO_{2e}$ for HGVs (based on estimated 75% compressor run time). This covers articulated and non-articulated goods vehicles but does not include vans where the refrigeration system is likely driven by the vehicle engine.

CCF (2021) estimate that there are 30,000 refrigerated trailers/semi-trailers (articulated HGVs) operated by UK based transport businesses and a further 15,000 rigid (non-articulated) HGVs and 25,000 vans (LGVs). If we assume there are a total of 70,000 TRUs and each TRU produces the same emissions as that calculated previously, this gives emissions of 1.02 $MtCO_{2e}$. This aligns relatively well with data from SKM Enviros (2011) who estimated 1.2 $MtCO_{2e}$ of indirect emissions from refrigeration used in food transport in 2010.

The emissions were considered to be between the 1.02 $MtCO_{2e}$ calculated using a number of different sources and 1.2 $MtCO_{2e}$ estimated by (SKM Enviros, 2011). A medium confidence was attributed to this data.

Marine refrigeration (fishing)

According to Gabrielii and Jafarzadeh (2020) refrigeration is a small proportion of the GHG emissions of UK fisheries. Primary production was in most cases the largest contributor with transport the largest contributor in some cases.

According to the National Atmospheric Emissions Inventory (NAEI) fishing vessels emitted 0.78 $MtCO_{2e}$ in 2019 due to their fuel use. It is unknown what proportion of this is used for refrigeration. However, in a study on Norwegian seafood products (Ziegler et al., 2013)., fuel use accounted for 63% to 87% and refrigerant leakage 13% to 37% of total GHG emissions.

It has not been possible to determine a value for the emissions of refrigeration from fishing vessels, however, it appears that this is small compared to that from road transport and therefore in this analysis has been ignored.

3.1.7 Domestic (in the home)

DUKES shows energy consumption from 4 types of domestic cold appliances. These were chest freezers, fridge-freezers, refrigerators and upright freezers (BEIS 2020). The total energy consumption for these appliances in 2019 was 10.75 TWh. As this data is direct and from Government statistics with no further analysis required, this value is given high confidence.

Table 1 shows the refrigeration energy consumption in the cold chain sectors and the emissions based on 2019 electrical grid carbon factors.

Table 1. Energy consumption and emissions.

Sector	Sub-sector	Energy (TWh)	Emissions ($MtCO_{2e}$)	Reference	Confidence
Agriculture and fisheries		0.4 - 0.44	0.09-0.10	DUKES, 2019. SKM Enviros, 2011). Warwick, 2007.	High
Food and drink manufacture	Food manufacture	2.49	0.55	DUKES, 2019.	High
Food and drink manufacture	Drink manufacture	0.59	0.13	DUKES, 2019.	High
Cold storage		1.32	0.29	CCAs 2017-18	High
Retail		6.96-7.36	1.53	BEIS, 2016.	Medium
Food service	Food and drink	4.16-7.89	0.92-1.74	SKM Enviros 2011. Calculation from many sources.	Medium
Food service	Drink	1.00	0.22	SKM Enviros, 2014.	Medium
Refrigerated transport	Land		1.02 – 1.2	Tassou et al., 2009. DEFRA,	Medium

				2012. SKM Enviros, 2011	
Refrigerated transport	Fishing		<0.78	NAEI, 2019	Low
Domestic		10.75	2.37	DUKES, 2019.	High
Total		**26.67-30.84**	**6.9 – 7.9**		

From the values shown in Table 1 the refrigeration energy consumption of the UK food cold chain is between 26.7 and 30.8 TWh in 2019, leading to carbon emissions of 6.9 to 7.9 $MtCO_{2e}$.

The Building Energy Efficiency Survey (BEES) reports on the non-domestic building stock in England and Wales in 2014–15 (BEIS, 2016). This covers all energy usage in retail, industrial, storage and hospitality. They reported that cooled storage (for storage of food and drink) used 10.79 TWh/year of energy. This is lower than the range of 15.92 to 20.09 TWh presented in Table 1 once domestic refrigeration has been removed from the figures.

Figure 1 shows the electrical energy consumption (TWh) of refrigeration in the food sectors. Where there is a range of values, the average was used. Refrigerated transport is excluded from this chart, as the energy consumption is predominantly from diesel, not electricity.

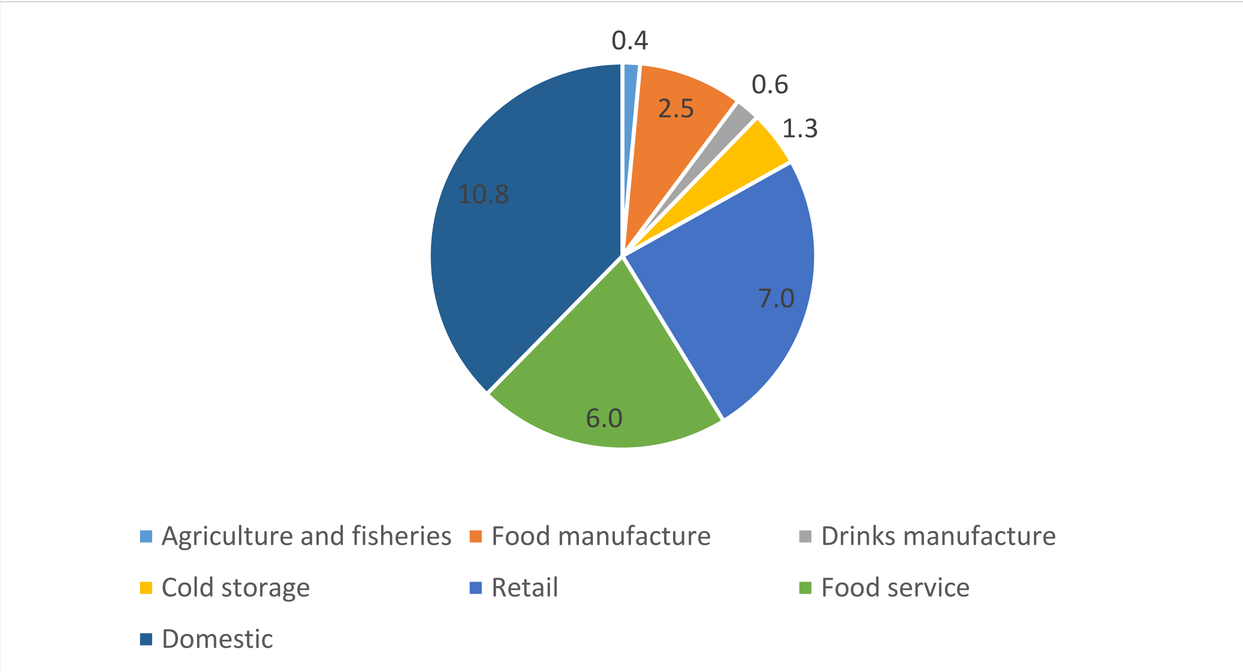

Figure 1. Electrical energy consumption (TWh) of refrigeration in the food sectors.

3.2 Refrigerant emissions

The EU F-Gas regulation came into force on 1st January 2015. The regulation introduced a ban on the installation of new equipment using refrigerants with a global warming potential (GWP) of 2500 or more from 2020; and also a ban on using virgin refrigerants for servicing from 2020. However, reclaimed refrigerant can be used for servicing up to 2030. This has had the greatest effect on systems using R404A which has a GWP of 3922 and was the most common refrigerant in many sectors before 2015.

BRA (2018) stated that at the time of publication there were 12,000 to 20,000 R404A systems in Britain, roughly half being large supermarket systems driven by multi-compressor packs, and the other half driven by condensing units. These systems are used on cold stores of all sizes, preparation rooms, convenience stores and process cooling. Analysis of information from the BRA Annual Statistics and collection and further discussions with the information providers for the survey and end users has given an estimate in excess of 11 000 tonnes of R404A being deployed throughout the food chain in the UK as at 2015. No further update of the quantity of R404A used has been found.

3.2.1 Agriculture and fisheries

The UK GHG Inventory shows emissions for different parts of agriculture, but does not differentiate directly for direct emissions from refrigeration. The study by SKM Enviros (2011) estimated 0.05 $MtCO_{2e}$ of direct emissions from agriculture. No other studies could be found. A confidence of medium was given to this value.

3.2.2 Food and drink manufacture

This sector typically has very large systems, that can be blast freezers, glycol chillers etc., often with in excess of 500 kg of refrigerant. However, there are also medium sized systems with typically 10 to 100 kg of refrigerant that can be used for cooling product or short term cold storage.

The only data that could be found for direct emissions for food manufacturing only (not cold storage) was from SKM Enviros (2011), who estimated 0.89 $MtCO_{2e}$ of direct emissions for food and drink manufacture. This is based on 2010 data and is made up of 0.54 and 0.35 $MtCO_{2e}$ from HFCs and HCFCs respectively. A medium confidence is associated with this value.

3.2.3 Cold storage

These systems tend to be large industrial systems commonly using ammonia. This sector tends to maintain temperature, not reduce it, although some sites have blast freezers.

The only data that could be found for direct emissions for cold storage only was from SKM Enviros (2011), who estimated 0.18 $MtCO_{2e}$ of direct emissions. A medium confidence is associated with this value.

3.2.4 Industrial (food manufacturing + cold storage)

The UK GHG Inventory shows emissions from industrial systems. This includes industrial process refrigeration (not necessarily food) and cold storage. Larger systems tend to use ammonia which has a GWP of 0.

According to the UK GHG Inventory for 2019 industrial refrigeration accounted for 1.34 $MtCO_{2e}$ of emissions. This includes food factories, cold stores, petrochemicals, pharmaceuticals, printing, and plastics. It is assumed that the food manufacturing and cold storage industry represents approximately 75% (1.01 $MtCO_{2e}$) of industrial refrigeration facilities, with the remaining 25% being in the chemical and pharmaceutical industries (Oko-Institut et al., 2021).

The sum of food and drink manufacture (section 3.2.2) and cold storage (section 3.2.3) is 1.07 MtCo2e. This matches closely with the value from this section. Therefore a high confidence is associated with this value.

3.2.5 Land transport refrigeration

Data from the UK GHG Inventory shows emissions from large trucks and iso-containers of 0.23 $MtCO_{2e}$ and vans and light trucks of 0.02 $MtCO_{2e}$ (total of 0.25 $MtCO_{2e}$). As this data came direct from government statistics a high confidence is associated with it.

3.2.6 Marine refrigeration (fishing)

Ziegler et al (2013) reported that modern pelagic vessels have cooling systems that use environmentally harmless refrigerants (e.g. ammonia) and only a small proportion of pelagic vessels were still using the hydrochlorofluorocarbon (HCFC) R22. R22 is still however common in demersal vessels.

Data from the UK GHG Inventory shows emissions from marine refrigeration of 0.44 $MtCO_{2e}$. As this data came direct from government statistics a high confidence is associated with it.

3.2.7 Retail

According to the BRA (BRA 2018) there were 8,000 to 12,000 multi evaporator refrigeration systems in retail premises in the UK. In addition, there were a similar number of single compressor systems in commercial and/or retail premises. Whilst progress has been made in converting these systems away from R404A, a significant proportion still (at the time of publication) use R404A as the refrigerant.

large supermarkets tend to use centralised “pack” systems. In small shops there is widespread use of integral systems and small split systems (with a remote condensing unit serving one or more display cases) (SKM Enviros ,2011).

According to Lamb (2021) about a quarter of retailers’ systems use CO_2 as the refrigerant.

The only data on direct emissions for commercial refrigeration excluding food service that could be found were those from SKM Enviros (2011) who estimated 3.0 $MtCO_{2e}$ of direct emissions in retail, 2.6 $MtCO_{2e}$ from HFCs and 0.4 $MtCO_{2e}$ from HCFCs. A medium confidence was applied to this value.

3.2.8 Food Service

This sector is mainly small systems including integrals (e.g. drinks coolers, food display cases) and small split systems (e.g. cellar cooling in pubs and small walk-in cold stores).

The only data on direct emissions that could be found for food service refrigeration were again those from SKM Enviros (2014) who estimated 0.45 $MtCO_{2e}$, with 0.24 $MtCO_{2e}$ being from HFCs and 0.21 $MtCO_{2e}$ from HCFCs. A medium confidence was applied to this value.

3.2.9 Commercial including food service and retail

The UK GHG Inventory shows emissions from commercial systems. The emissions for this sector were reported as 3.19 $MtCO_{2e}$ in 2019. The sum of the retail (Section 3.2.7) and food service emissions (Section 3.2.8) was 3.45 $MtCO_{2e}$ which is similar to the value reported here.

These values are given a high confidence as they are from Government statistics.

3.2.10 Domestic

In 2013, 98% of all household refrigeration appliances were using isobutane (R600a) (VHK and ARMINES, 2015).

According to the UK Greenhouse Gas Inventory for 2019, domestic refrigeration emissions were 0.15 $MtCO_{2e}$. This value is given a high confidence.

Table 2 shows the refrigerant emissions in the cold chain.

Table 2. Direct emissions for cold chain sectors

Sector	Sub-sector	Refrigerant emissions ($MtCO_{2e}$)	Reference	Confidence
Agriculture and fisheries		0.05	SKM Enviros, 2011	Medium
Industrial		1.01	UK Greenhouse Gas Inventories, 2019 (Oko-Institut, 2021	High

Industrial	Food manufacture	0.89	SKM Enviros, 2011	Medium
Industrial	Cold storage	0.18	SKM Enviros, 2011	Medium
Refrigerated transport	large trucks and iso-containers	0.23	UK Greenhouse Gas Inventories, 2019	High
Refrigerated transport	vans and light trucks	0.02	UK Greenhouse Gas Inventories, 2019	High
Refrigerated transport	Fishing	0.44	UK Greenhouse Gas Inventories, 2019	High
Commercial	Centralised Supermarket Refrigeration Systems	1.92	UK Greenhouse Gas Inventories, 2019	High
Commercial	Small Hermetic Stand-Alone Refrigeration (Integral) Units	0.12	UK Greenhouse Gas Inventories, 2019	High
Commercial	Condensing Units	1.16	UK Greenhouse Gas Inventories, 2019	High
Commercial	Retail	3.0	SKM Enviros, 2011	Medium
Commercial	Food Service	0.45	SKM Enviros, 2011	Medium
Domestic		0.15	UK Greenhouse Gas Inventories, 2019	High
Total		**5.1**		

Total emissions from refrigerants were estimated at 5.1 $MtCO_{2e}$.

Figure 2 shows the refrigerant emissions ($MtCO_{2e}$) in each of the food sectors. Over half of the emissions (56%) are from retail. The smallest emitter is agriculture and fisheries at 0.9%.

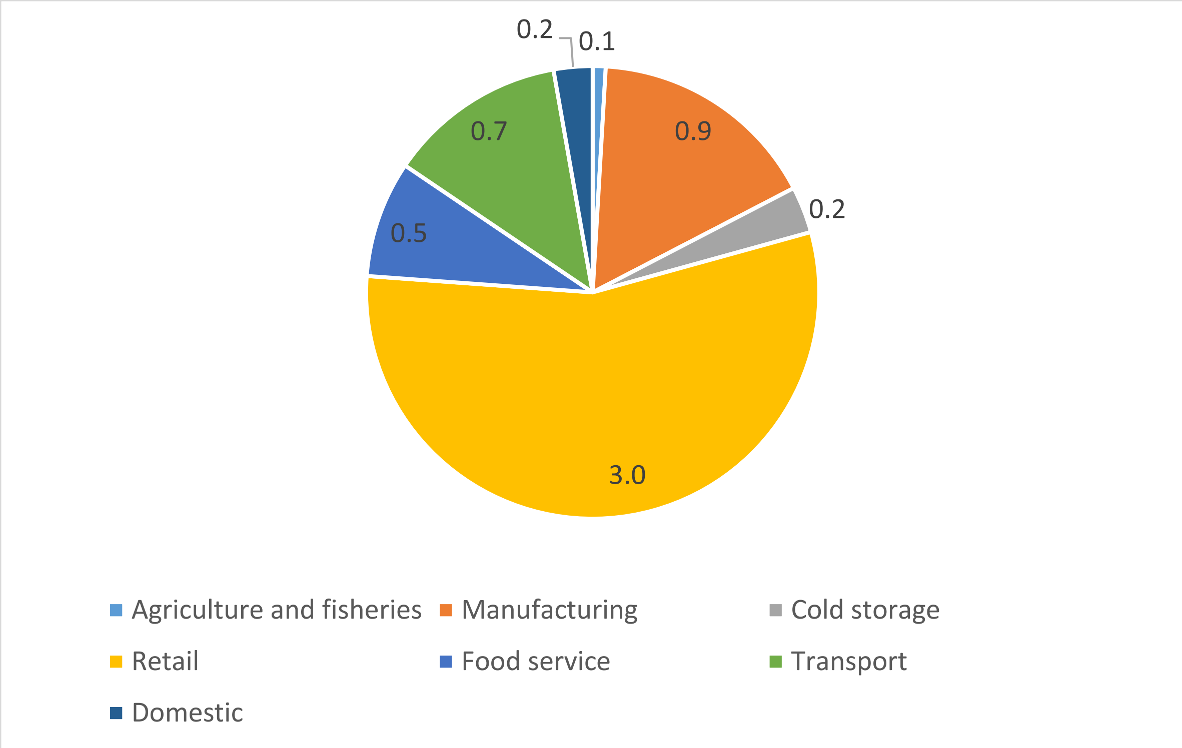

Figure 2. Electrical energy consumption (TWh) of refrigeration in the food sectors.

4 DISCUSSION AND CONCLUSIONS

Refrigeration in the food cold chain was estimated to consume approximately 28.6 TWh/a of electrical energy. Consumption tends to increase towards the consumer end of the cold chain, with 1.5% in agriculture and fisheries and 38% in domestic refrigeration. Emissions caused by the generation of the electrical power, using 2019 electrical emissions factors, plus the emissions from road transport vehicles attributed to the TRUs were between 6.9 and 7.9 $MtCO_{2e}$.

Emissions from the refrigerants within the refrigerated equipment were estimated to total 5.4 $MtCO_{2e}$. More than half (56%) of this was from retail refrigeration. Agriculture and fisheries at 0.9% and domestic at 2.8% were the sectors with the lowest direct emissions.

Further work will project these emissions to 2050 under different scenarios. It is clear from these results that energy consumption of domestic refrigeration and refrigerant emissions from retail refrigeration are the sectors which require the greatest focus.

5 ACKNOWLEDGEMENTS

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