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Projecting the carbon emissions from refrigeration used in the UK food industry to 2050

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ABSTRACT

The impact to food cold chain greenhouse gas emissions from changes to population, climate, equipment efficiency, f-gas phase-downs, electrical grid carbon intensity and electrification of transport refrigeration up to 2050 were predicted using a 2019 baseline from a previous study. GHG emissions were projected to reduce by 98% from 2030 to 2050. This is due to decarbonisation of the electrical grid, electrification of diesel powered transport refrigeration units (TRUs) and f-gas phase down. Population and increased ambient temperature only have a marginal effect (7.2% increase to 2050). Although GHG emissions reduce, the electrical demand on the grid is projected to increase by 9.9% from 2030 to 2040 and then remain relatively stable. This is due to increased electrical demand as two thirds of HGV diesel TRUs are converted to electric.

Keywords: Greenhouse gas emissions, Cold Chain, Global Warming

1. INTRODUCTION

The food and drink industry is the largest manufacturing sector in the UK by turnover. The agri-food sector was worth £116 bn in 2020 and in 2022 employed 4.1 m people. Total consumer expenditure on food drink and catering in 2021 was £240 bn and the value of food and drink exports was £20.2 bn (DEFRA, 2022). According to Garnett (in 2007) food refrigeration accounted for about 2.4% of the UK's greenhouse gas emissions. More recent information from Ravishanka et al (2020) estimated food refrigeration to be responsible for 2-4% of the UKs total GHG emissions.

Cold chains are energy intensive. According to Foster et al (2022) refrigeration in the UK food cold chain accounted for approximately 28.6 TWh/a of electrical energy consumption. Energy based emissions caused by the generation of the electrical power, plus the diesel for transport refrigeration units (TRUs) were between 6.9 and 7.9 $MtCO_{2e}$ per annum.

Refrigeration systems use refrigerants, which often have high global warming potentials (GWPs). These refrigerants tend to leak into the atmosphere. According to Foster et al (2022) emissions from leakage of refrigerants from food cold chain refrigerated equipment was 5.4 $MtCO_{2e}$.

Nothing stays constant in a developing world, and this is especially true at this time of external changes, e.g. climate change and the necessary transitions in energy and other high greenhouse gas emitting sectors. The UK has a Net Zero Strategy (HM Government, 2021). This strategy sets out policies and proposals for decarbonising all sectors of the UK economy to meet the net zero target by 2050.

Audsley (2010) assessed GHG emissions from the UK food system and investigated the scope to reduce them by 2050. They stated that if the UK food chain is to make a proportionate contribution to the UK's target of reducing its overall emissions by 80% by 2050, then policy makers will need to put in place a combination of measures that change not only how we produce and consume food, but also what it is we consume. This study did not look specifically at the refrigeration aspects of the food chain.

According to Griffin et al. (2016) the food & drink sector produces a wide range of products, making use of many different processes. Therefore, decarbonisation of this sector will be more challenging than sectors with few generic processes.

Energy used by refrigeration is affected by the ambient temperature. Hart et al (2019), showed the energy penalty of increased ambient temperature on 30 supermarket stores in summer 2018 compared to a baseline of 2016/17. They found that as a general rule, a 2°C increase on today's average summer temperatures will increase the supermarket estate's refrigeration energy consumption by 6.1% across June-August.

According to Tassou et at al. (2014) significant progress in energy efficiency has been made in recent years but potential still exists through improvements in the efficiency of refrigeration systems, refrigeration and HVAC system integration, heat recovery and amplification using heat pumps and demand side management.

The Low Emissions Analysis Platform (LEAP), is a software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. Duan et al (2019) investigated carbon emissions from buildings in China using the LEAP method. They showed that carbon emissions will reach a peak in 2030 and that heating, cooling, and cooking contribute 55.7%, 18.9%, and 17.3% of carbon emissions, respectively. LEAP is primarily an energy sector modelling tool. Other tools, such as EX-Ante Carbon Balance Tool (EX-ACT) (FAO, 2023) quantifies the amount of greenhouse gas released or sequestered from agricultural production.

Davis and Gertler (2015) used data from Mexico between 2009 and 2012 to characterize empirically the relationship between temperature, income, and residential air conditioning. They showed that both ambient temperature and income increase the use of air conditioning, but income has the biggest share. They mention that increased efficiency and low carbon electricity could substantially mitigate these issues, but do not consider it in their predictions.

Höglund-Isaksson et al. (2012) produced a low carbon roadmap for EU. This paper focused on non-CO2 greenhouse gases. They showed that between 2005 and 2050, baseline emissions were expected to fall by 26 percent in the Reference scenario and by 44 percent in the Decarbonization scenario.

Griffin et al. (2016) investigated industrial energy use and carbon emissions reduction from a UK perspective. They focused on the supply of low temperature heat. This included steam system efficiency and the increased use of both CHP plants and heat pumps. They showed that the Food and Drink sector had 7% of the total industrial sector emissions.

The aim of this work was to project only UK food refrigeration based (cold-chain) emissions by projecting the baseline emissions from Foster et al (2022) to 2050. The impact of higher ambient temperatures due to climate change, increases in population, improvement in energy efficiency, phase down of f-gases, decarbonisation of the electrical grid and electrification of TRUs were all taken into account.

2. METHOD

Carbon emissions from refrigeration in the UK food and beverage cold chain were projected from 2020 data calculated in previous work (Foster et al, 2020) to 2030, 2040 and 2050. The effect of changes in emissions caused by population, climate change, equipment efficiency, f-gas phase-downs, electrical grid carbon intensity and electrification of TRUs were considered. The assumptions used are described in the following sections.

2.1. Population

The future population of the UK was obtained from ONS (2022). The data only extended to 2045, so a curve fit of the data was used to project the population to 2050. The next step was to consider the effect that changing population would have on emissions. It was assumed that population would be directly correlated to all emissions, such that a 10% increase in population would increase all emissions by 10%. The rational for this assumption is that 10% more people will use 10% more domestic refrigerators and consume 10% more food, using 10% more of all refrigeration covered by both Scope 1 and 2 emissions.

2.2. Climate change

Only the effect of ambient temperature on the energy consumption of refrigeration systems was considered. Energy consumption encompasses all Scope 2 emissions and the Scope 1 diesel emissions from TRUs. UK climate projections from the Met Office (2022) were used to predict ambient temperature increase in the UK in the periods 2020-2039, 2030-2049 and 2040-2059. The representative concentration pathway (RCP) 4.5 (50th percentile) value was used. This is one of the 4 pathways used in climate modelling and research for the IPCC fifth Assessment Report. RCP 4.5 is an intermediate scenario, where emissions peak around 2040, then decline. This predicted average temperature in the UK to increase by 0.1, 0.3 and 0.5°C by 2030, 2040 and 2050 using 2020 as a baseline.

The effect on emissions was assumed to be caused by increases in both the temperature around the equipment, causing extra heat to be removed and also increased heat rejection temperature, reducing the Carnot efficiency of the refrigeration system.

To calculate the effect of increased ambient temperature two methods were compared. The first method was to use a cold store warehouse model (Foster et al, 2016) and increase the ambient temperature at each point in time throughout the year. The average yearly temperature increase from RCP was applied through the year. It was found that a 1 K increase, increased chilled cold stores energy consumption by 2% and frozen cold stores by 3%.

The other method was to consider that a 1 K temperature reduction causes a 6% power reduction in domestic refrigeration, as presented by ISIS, 2007. We assumed that the ambient temperature in the kitchen is maintained at a constant temperature for the coldest 6 months of the year due to heating, therefore, the energy consumption of the domestic refrigerator will not change during the period. For the warmest 6 months of the year when the heating is off, the energy consumption of the refrigerator will increase by 6% for a 1 K ambient temperature increase. Therefore, the yearly increase in energy consumption of the domestic refrigerator for a 1 K increase in ambient temperature was 3%.

Both these methods gave very similar results and therefore an energy increase of 3% for a 1 K temperature increase was used for all the refrigeration sectors.

2.3. Grid electrical emission carbon intensity

Electricity emissions factors from BEIS (2021) were used to calculate GHG emissions from electricity up until 2050.

2.4. F-gas phase down

Due to current f-gas regulations (EC, 2014), refrigeration systems are moving away from high global warming potential (GWP) HFCs to low GWP refrigerants. BEIS have projected carbon emissions reductions to 2040 (BEIS, 2020). They projected HFC emissions based on (i) short-term company planning information and (ii) long-term replacement of F-gases due to the 2014 EU F-gas regulation.

2.5. Equipment efficiency

There is a general trend for efficiency improvements in refrigerated equipment, as well as other equipment. This trend is guided by policy and energy prices. Not all refrigerated equipment is likely to undergo the same efficiency improvements with time, as different equipment is covered by different policy, and cost of energy has a different impact to different end users. A focus was placed on domestic refrigeration, as this is the largest current Scope 2 (electrical energy) emissions sector.

Projections for domestic refrigeration were carried out for the UK Department for Business, Energy and Industrial Strategy (BEIS) by ICF International. The energy consumption includes the impact of the Eco-design directive which requires mandatory efficiency improvements. Values beyond 2035 assume continuous improvement (i.e. refrigeration product manufacturers naturally improving the energy efficiency of their products in absence of policy).

Regarding stock levels, Mintel data between 2007 and 2018 was used to extrapolate ownership of 4 types of domestic refrigerator (chest freezer, upright freezer, fridge, fridge-freezer). This included a small increase in the total number of domestic refrigerators in use and more significant changes in the type of domestic refrigerator.

2.6. Transport

It was assumed that the targets in the Cold Chain Road to Net Zero plan were met (CCF, 2021). This assumes for LGVs that electric phase in of the TRUs starts in 2020 and is fully implemented in 2035. We assume an even implementation in each year between these dates. The same assumption is used for HGVs, but the dates are 5 years later (2025 and 2040). We have assumed 7% of TRU emissions are from light goods vehicles LGVs and 93% from heavy good vehicles (HGVs). This is based on 7% of f-gas emissions from road transport from LGVs from NAEI (2022). It is assumed that as diesel TRUs are being replaced by electric, the diesel emissions (Scope 1) are replaced by emissions from electrical production (Scope 2), assuming the same energy used for a diesel and electric TRU.

2.7. Total emissions

To calculate the total emissions, the effect of each of the parameters above was applied to each of the emission types and sectors, as shown in Eq (1) to (3).

$$E_f^y = E_f^{2020} \text{ x } C_p^y \text{ x } C_{fg} \qquad \text{Eq. (1)}$$

$$E_{s2}^y = E_{s2}^{2020} \text{ x } C_p^y \text{ x } C_T^y \text{ x } C_{gi}^y \qquad \text{Eq. (2)}$$

For transport C_{ei}^y is excluded as already included previously. For domestic C_p was excluded as already included previously and was replaced by C_{ee}^y

$$E_d^y = E_d^{2020} \text{ x } C_p^y \text{ x } C_T^y \qquad \text{Eq. (3)}$$

3. RESULTS

3.1. Population

Purely based on population growth we would expect the GHG emissions to increase by 6.2% from 12.90 to 13.70 $MtCO_{2e}$ between 2020 and 2050 (Figure 1).

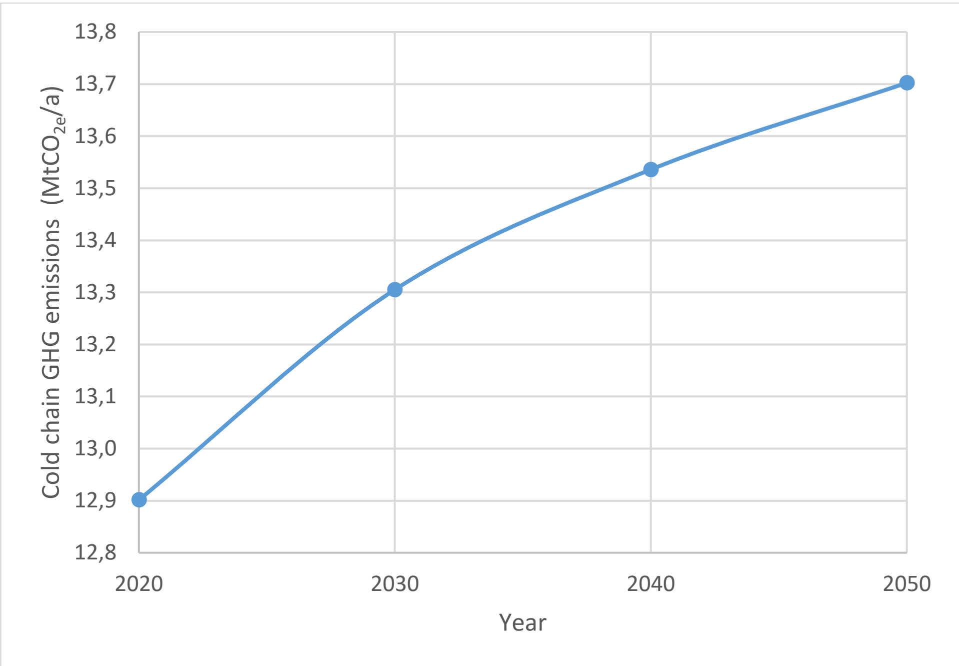

Figure 1: Effect of population on total refrigeration-based emissions

3.2. Climate change

Purely based on average temperature increase due to climate change (0.1, 0.3 and 0.5°C by 2030, 2040 and 2050 respectively) we would expect refrigeration energy based GHG emissions (Scope 2 and diesel for TRUs) to grow by 1.5% from 7.51 to 7.62 $MtCO_{2e}$ between 2020 and 2050 Figure 2.

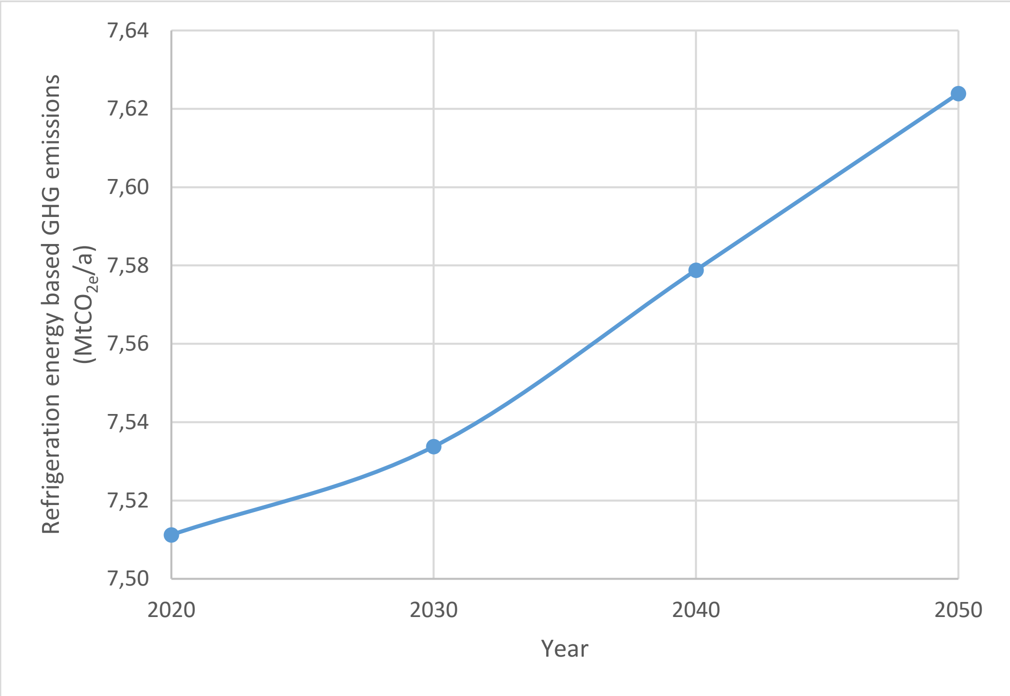

Figure 2: Effect of climate change on refrigeration energy-based emissions

3.3. Grid electrical emission carbon intensity

Electrical GHG emissions are projected to reduce in the UK due to decarbonisation of the electrical power grid. Purely based on grid decarbonisation, we would expect refrigeration grid electrical energy based GHG emissions (Scope 2) to reduce by 97% from 6.39 to 0.21 $MtCO_{2e}$ between 2020 and 2050 (Figure 3).

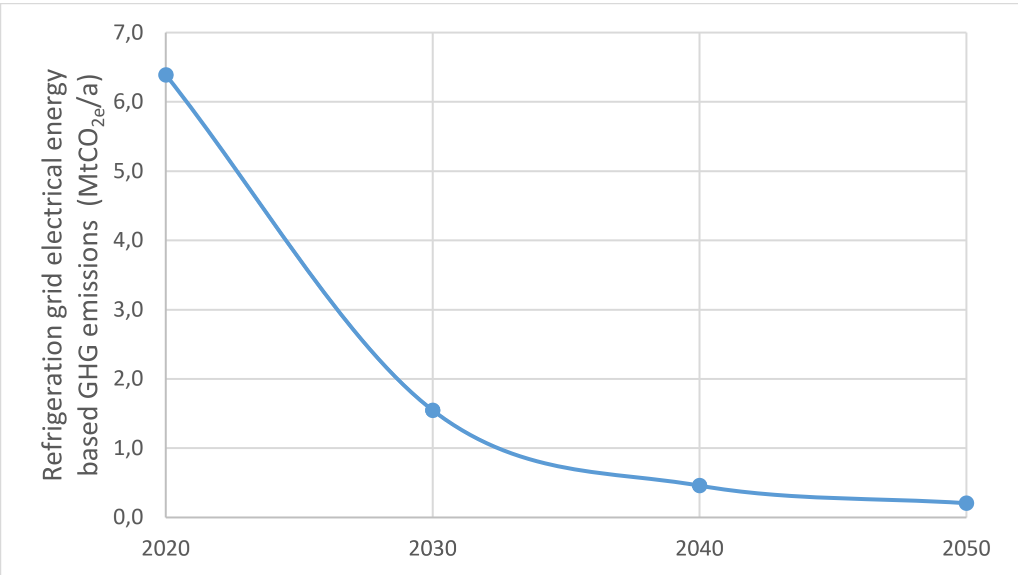

Figure 3: Effect of grid electricity carbon intensity on refrigeration electrical energy-based emissions

3.4. F-gas phase down

Fugitive GHG emissions are projected to reduce in the UK due to industry moving to low GWP refrigerants partly caused by f-gas regulations. Purely based on reduced GWP refrigerants we would expect fugitive emissions to reduce by 99% from 5.39 MtCO2e to 0.05 MtCO2e between 2020 and 2040 (Figure 4). BEIS data did not allow projections beyond 2040, however as the emissions were almost zero in 2040, it would have little impact.

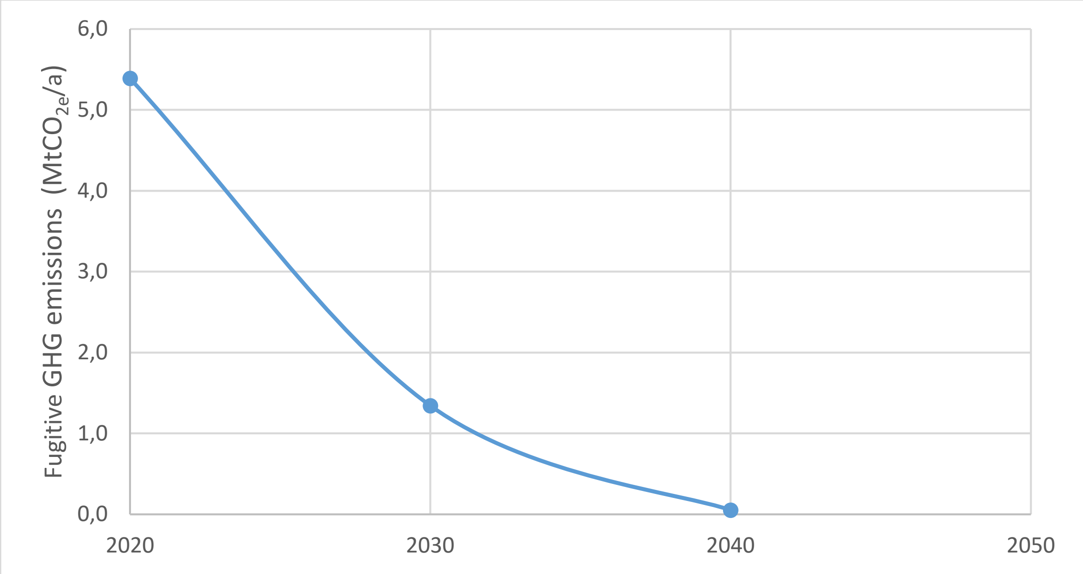

Figure 4: Effect of f-gas phase down on fugitive emissions

3.5. Equipment efficiency

Domestic electrical energy based GHG emissions are projected to reduce by 34% from 2.37 to 1.58 $MtCO_{2e}$ between 2020 and 2050 in the UK due to improvements in efficiency. This projection takes into account changes in the number of types of appliances and thus already includes effect of population change (Figure 5).

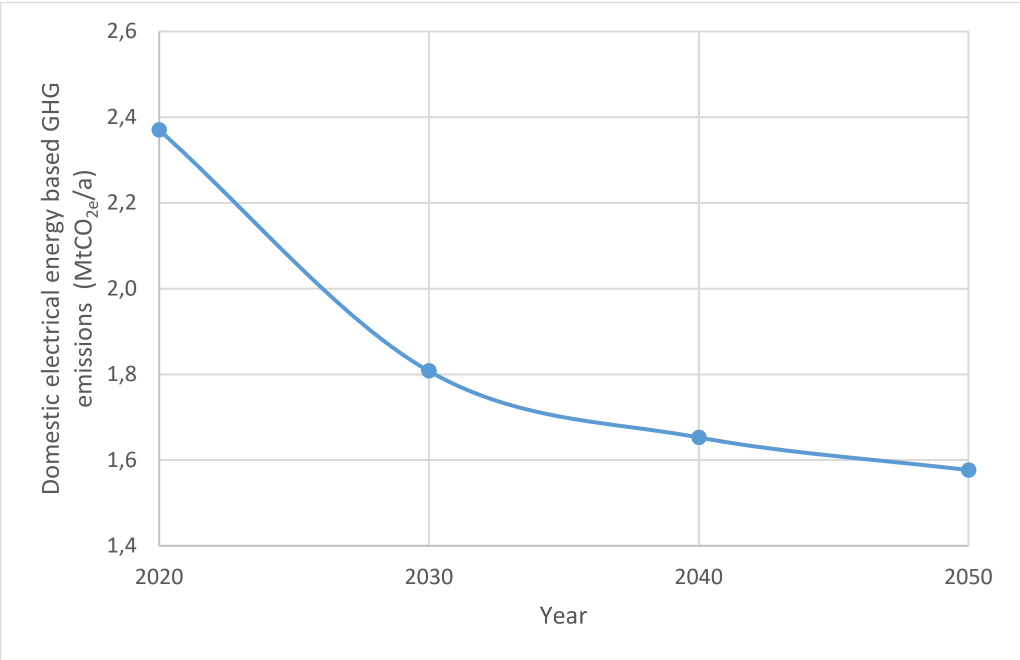

Figure 5: Effect of equipment efficiency and changes in number and type of appliance and population change on domestic refrigeration electrical based emissions

3.6. Transport

TRU energy based GHG emissions are projected to reduce by almost 100% from 1.12 to 0.03 $MtCO_{2e}$ between 2020 and 2050 in the UK due to changeover from diesel to electric vehicles. This projection includes the changes in grid electrical emission carbon intensity over this period (Figure 6).

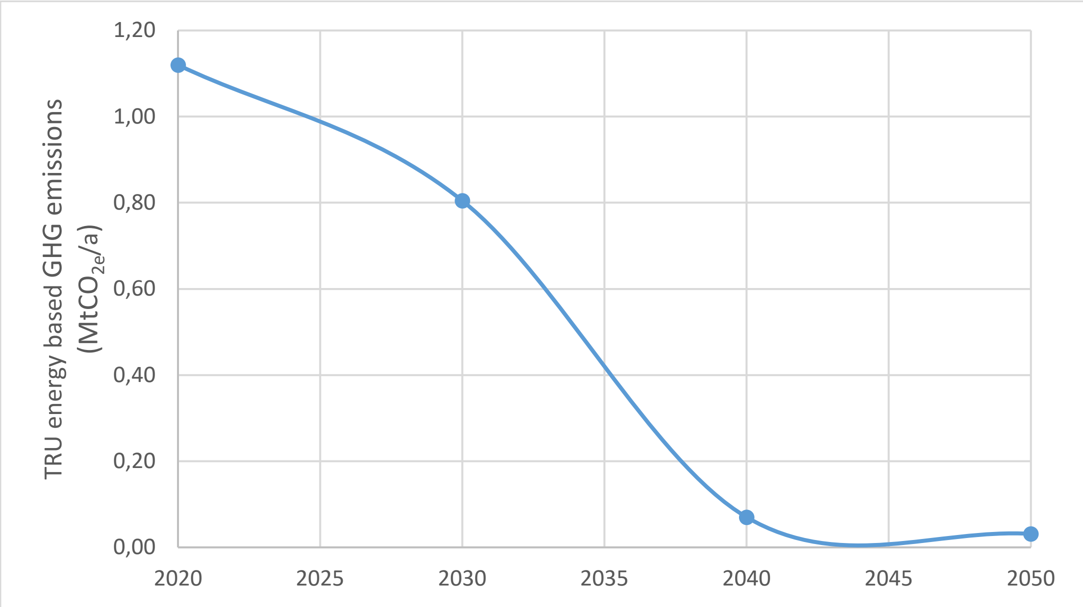

Figure 6: Effect of electrification of TRUs on GHG emissions

3.7. Total emissions

When all of the projections are taken into account, the total cold chain GHG emissions reduces by 98% from 12.90 to 0.22 $MtCO_{2e}$ (Figure 7).

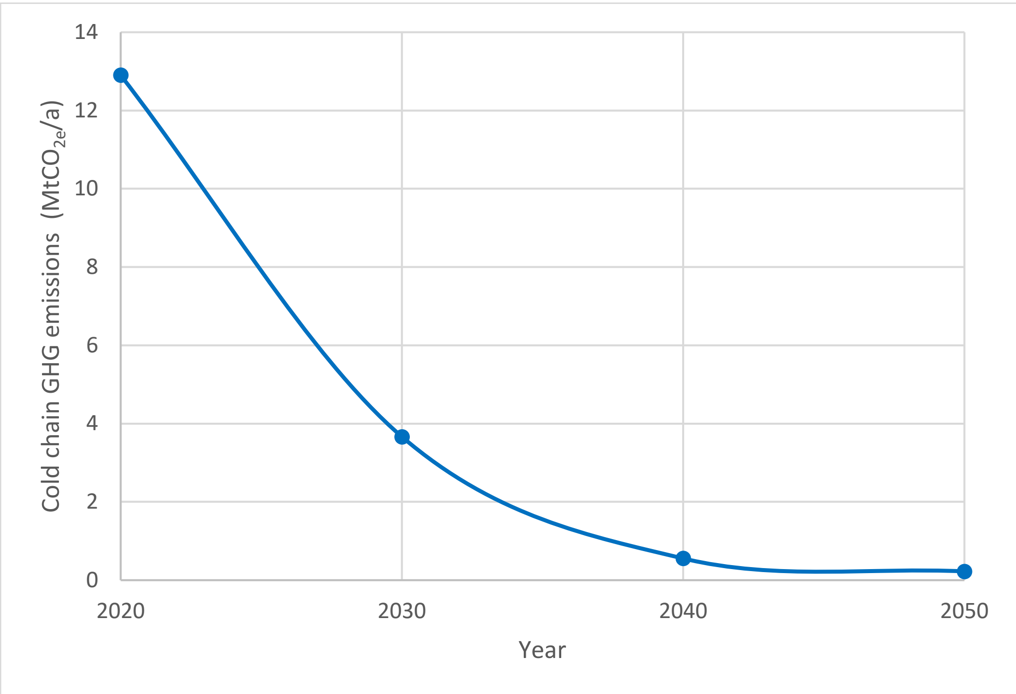

Figure 7: Effect of all parameters on total emissions

3.8. Electrical demand

The decarbonisation of the electrical grid is dependent on the demand on it, the larger the demand, the more it costs to decarbonise. The UK food based refrigeration electrical demand remains reasonably constant (29.5

to 29.2 TWh) from 2020 to 2030 but then rises to 32.1 TWh in 2040 and then stays reasonably constant until 2050 (Figure 8). If it were not for the electrification of TRUs, the electrical demand would reduce to a minimum of 27.3 TWh in 2040 due to energy efficiency improvements in domestic refrigeration, alone. Other refrigeration efficiencies measures are likely to further decrease demand, but at the same time the movement from natural gas to heat pumps will increase demand. The UK government has ambition to grow the market in heat pumps to 600,000 installations per year by 2028 (BEIS, 2023).

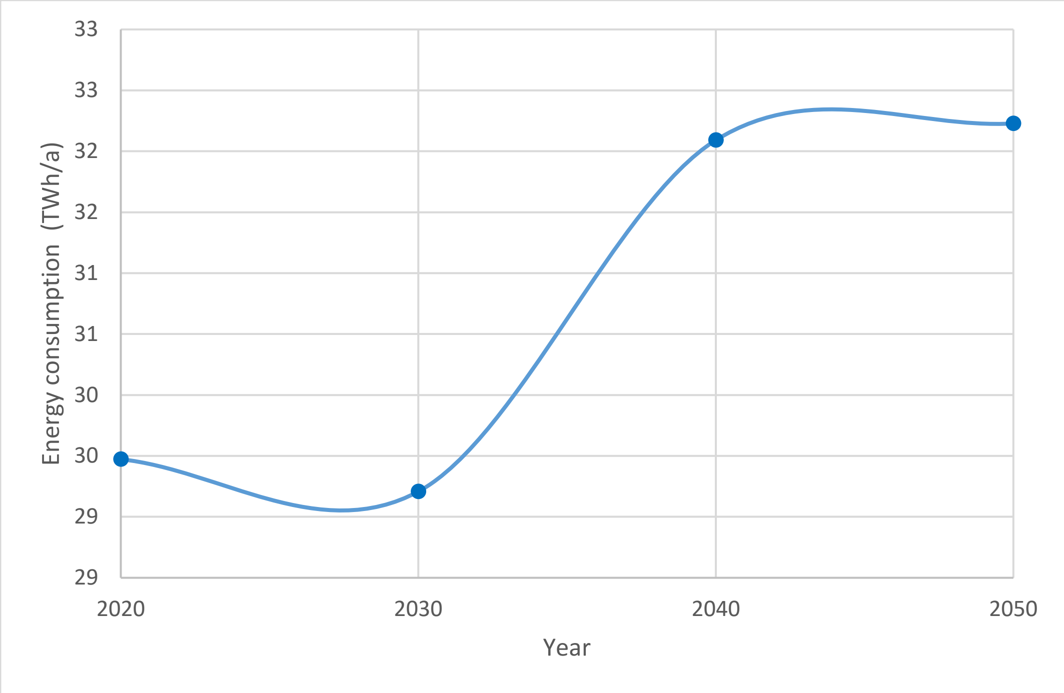

Figure 8: Effect of all parameters on refrigeration based electrical demand on the grid

4. DISCUSSION

The UK emissions projections are mostly dependant on three factors, decarbonisation of the grid, low GWP refrigerants and electrification of TRUs. All are discussed in more detail below.

4.1. Decarbonisation of the grid

The UK Government have stated a plan to decarbonise the grid by 2035, which is faster than the projections provided by BEIS used in this study. This is technically possible, but will require significant increases in renewables, e.g. wind and solar as well as energy storage. It will also involve large investments in power infrastructure (e.g. cabling and transformers) and the political will to pay for this plus the legislation to enable rapid application (for example changed in planning laws). All this is made more difficult if energy consumption continues to rise, as fossil fuel transport and gas heating become electrified.

4.2. F-gas phase down

The f-gas phase down (EC, 2014) will reduce CO_{2e} of all gasses in use to 63% of the baseline by 2018-2020 and 21% of the baseline by 2030. Therefore, if we assume GHG emissions follow this trend, we would expect a 67% reduction from 2020 to 2030 and then emissions remaining static. In this study, we have predicted a 75% reduction by 2030 and a 99% reduction by 2040.

The trend is for domestic refrigeration to quickly reach near zero Scope 1 fugitive GHG emissions as old refrigerators get replaced by new refrigerators using hydrocarbons. However, GHG emission for domestic are a very small proportion (1.2%) of the total Scope 1 fugitive emissions.

For commercial systems, which emit 55% of the fugitive emissions, large centralised systems will use CO_2 and small integral systems will use HCs. There will, however, be some systems too small to be financially viable to use CO_2 and too large to be safe for HCs, which will need to use HFC/HFO blends with a GWP <150. Without further legislation, this may stop the fugitive emissions reducing to near zero by 2050.

For industrial systems (33% of fugitive emissions), large systems are likely to be ammonia, however, the current legislation allows for GWP < 2500. This is likely to impede the reduction of fugitive emissions in this sector for smaller systems. However, they will be affected by the phase down which will decrease access to high GWP refrigerants as well as increase their cost.

For TRUs (11% of fugitive emissions) there are no product bans, but there are service bans precluding R404A in large systems (>10 kg), however most TRUs use less than this, therefore the f-gas regulations do not have much impact on reducing fugitive emissions in this sector. However, CCF (2021) have an industry target to not sell TRUs with a GWP >300 by 2025 and to completely phase out TRUs with GWP >300 by 2035.

4.3. Transport

The UK government is planning to ban sale of new petrol and diesel cars and vans by 2030 and hybrids by 2035. Currently 35% of new UK car registrations are electric vehicles. HGVs and to a smaller extent LGVs are still a long way behind electric car take up. According to SMMT (2022) battery electric LGV sales in December 2021 were 9.4% of diesel sales, this is low, but rapidly rising as it was only 3.8% in the whole of 2021 and 1.9% in 2020. For all refrigerated LGVs to be electric by 2035 appears optimistic considering a lifetime of these vehicles of between 9 and 15 years (Brown, 2021) as this would require new purchases to be almost entirely battery electric from now on.

According to Department for Transport (DfT,2022) 54,000 new HGVs were registered in 2019 and only 0.2% were electric or gas. To be entirely electric by 2040 will require a very large increase in purchases of electric HGVs that is possibly beyond the supply capability. However, it is possible that TRUs will electrify at a separate and faster rate than the propulsion systems. This is because many TRUs on trailers already use electric hook-up when parked. Therefore, it is possible battery or solar power is only required whilst the vehicle is moving. Bagheri et al. (2017) has shown that replacing a diesel-powered TRU with a battery electric one is feasible and a battery electric system is lighter than a diesel-powered system with fuel tank, reducing the emissions of the vehicle. Changing from fossil fuel to battery electric will also require large increases in public and private charging infrastructure.

5. CONCLUSIONS

Total UK refrigeration based GHG emissions are projected to reduce by 98% from 2030 to 2050. This is due to decarbonisation of the electrical grid, movement from diesel powered TRUs to electrically power and f-gas phase down. Increases in emissions due to population and increased ambient temperature only have a marginal effect (7.2% increase from 2020 to 2050).

Although GHG emissions reduce, the electrical demand on the grid is projected to increase by 9.9% from 2030 to 2040 and then remain relatively stable. This is due to increased electrical demand, as two thirds of HGV diesel TRUs are converted to electric.

The f-gas Directive will reduce fugitive emissions dramatically, however, there are still a number of sectors which are likely to use high global warming HFCs without further legislation. The new proposed revision of the regulation (EESC, 2022) should address some of these concerns, e.g. ban on all refrigerants with a GWP >5 after 2030 for, chillers, and refrigeration applications alternatives. Also, the proposed revision recommends a faster phase down (95% cut in 2030 and 97.5% cut in 2048).

Electrification of TRUs is not likely to meet CCF projections without a massive increase in investment in vehicles and charging infrastructure. This will also have a large effect on electrical energy demand on the grid at a time when the grid is trying to decarbonise.

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NOMENCLATURE

E	emissions ($MtCO_{2e}$)	fg	f-gas
C	coefficient (dimensionless).	f	fugitive
Superscripts:		gi	grid intensity
y	year of the projection		
Subscripts:			
d	diesel	p	population
ee	electrical efficiency	s2	scope 2
ei	electrical efficiency	T	temperature

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