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Emissions Assessment of Refrigerated Food Road Transport in the UK

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Why you should attend

- To gain insights into estimated energy use and emissions from road transport refrigerated units in the UK
- To have a better understanding of vehicle numbers and composition
- To understand trends in consumer shopping and how they affect the demand for transport refrigerated units

Abstract

Above 60% of food in the UK is dependent on the cold chain and an estimated 2 - 4% of the UK's total greenhouse gas (GHG) emissions is associated with food refrigeration [1]. Refrigerated vehicles are essential parts of the modern cold chain distribution system, particularly in linking farmers and consumers while extending perishable food's shelf life and helping meet the required regulatory temperature constraints. Transport Refrigeration Units (TRUs) are presently primarily powered by diesel fuel. The UK government is committed to Net Zero emissions by 2050 from all sectors, including transportation, hence decarbonisation of this sector is paramount.

The present paper aims to estimate the energy demand and emissions of the UK temperature-controlled transport using a bottom-up approach. Only energy and emissions associated with the TRUs of road refrigerated transport are considered, while traction-related fuel is excluded. Depending on their sizes, refrigerated vehicles were categorised into cargo (motorcycles and tricycles), vans (<3.5 tonnes), trucks (>3.5 ≤ 18 tonnes) and trailers (>18 tonnes).

The study estimates the number of temperature-controlled vehicles in the UK to be around 158,934 ± 46,326. This includes 4,391 - 8,004 E-cargo bikes; 44,877 - 81,802 vans; 21,561 – 39,301 trucks and 41,778 - 76,152 trailers. Depending on the number of vehicles, the total annual energy and emissions associated with transport refrigeration units varied between 5.13 - 9.36 TWh and 1.44 - 2.62 $MtCO_2e$ respectively. Scope I emissions vary between 1.44 to 2.62 $MtCO_2e$ (0.20 - 0.36 $MtCO_2e$ from refrigerant usage and 1.23 - 2.26 $MtCO_2e$ from fuel use). The Scope II emissions which is the emissions associated with electricity consumption also varied between 446.2 and 813.4 tCO_2e.

1. Introduction

By 2030, the expected population growth could lead to a global increase in food production and energy demand by about 50% and 45%, respectively [2]. Meanwhile, climate change has imposed additional challenges to the already over-exploited finite resources' capacity to meet the projected growths. To avoid the worst outcomes of climate change, the world must limit global temperature rise to 1.5°C and attain Net Zero emissions by mid-century. The food and drink sector has a significant role to play since food systems emit about 15.8 $GtCO_2e$, equating to 30% of the world's GHG emissions. In particular, the global food miles account for about 3.0 $GtCO_2e$ of the total food systems emissions [3].

Therefore, governments worldwide, including the UK, have prioritised food security and resilient food systems. Consequently, the UK government has envisioned sustainable and secure food systems in 2030 in response to demographic and climate changes. The strategy mainly centres on reducing the resources used in the food system, reducing GHG emissions, and minimising food waste while ensuring the food system's competitiveness [4].

Meanwhile, "the farm to fork" chain in the UK is worth £120 billion, with the food and drinks manufacturing sector being the largest UK manufacturer, contributing £29 billion to the economy yearly and employing over 440,000 people. The UK's food system relies on imports; about 84% of fruits and 47% of vegetables were imported in 2019 [5]. Thus, making the UK food system dependent on transportation.

The literature suggests there is an increasing preference for frozen food consumption, primarily driven by longer shelf-life, lower price and preference for lower shopping frequency [6]. [6] For instance, within the UK, fresh products sales value dropped by 8.3% while frozen food sales value increase by +9.5% between 2022 and 2023 [7] and with right information on waste reduction and nutrition values about 42% of consumers are willing to buy more frozen foods [8]. According to the UK Cold Chain Federation (CCF), there is approximately 51% increased demand for products that pass-through temperature-controlled supply chain with a corresponding 62% increase in demand for environmental sustainability [9]. Therefore, there is increasing demand for the temperature-controlled transportation system. Refrigerated transport has the twin burden of emissions from traction and TRUs. Emissions in the transport refrigeration sector include direct emissions of refrigerants (fugitives) with high global warming potentials and emissions for powering the TRU, usually vehicle engine, separate diesel driven TRU or from electricity used to power TRU [10].

Understanding how many temperature-controlled vehicles are on the road and their contribution to GHG emissions is essential for planning appropriate and effective mitigation measures. It will also help monitor emissions reductions and substantiate policy measures once a good baseline has been established. Unfortunately, there is no accurate data on the number of refrigerated vehicles on UK roads. For instance, while CENEX [11] puts TRUs on the UK road at 100,000, Foster et al. [12] suggest 70,000 TRUs on the UK roads. Therefore, this paper aims to estimate the current fleet size and compositions of the temperature-controlled vehicles on UK roads. Using a bottom-up approach, including a survey of key stakeholders, the result is then used to estimate energy and emissions associated with the temperature-controlled road transport of the UK baseline year 2023.

2. Methodology

2.1 Vehicle size and composition

The analysis of fleet size and compositions of temperature-controlled supply chain in the UK and subsequent

assessment of associated energy and emissions are done following the approach detailed in Figure 1. The methodology included a desk-based study of existing literature to understand and analyse fleet size, compositions, and stakeholders involved in temperature-controlled transportation within the UK.

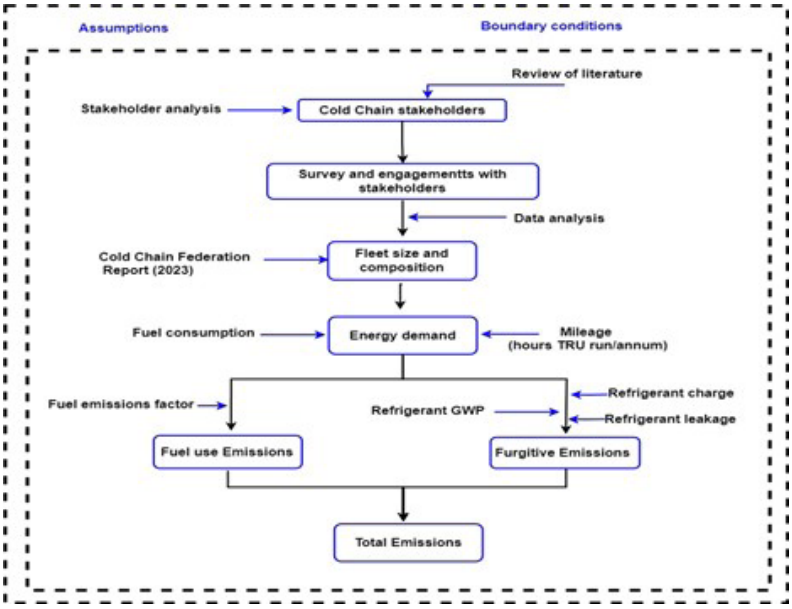

Figure 1: Approach to energy and emissions analysis of TRUs in the UK.

This was then followed by stakeholders' engagement and survey. The survey was conducted between 29th June and 1st September 2023, and the survey questionnaire was sent to 139 businesses across identified stakeholders. Businesses with direct control of refrigerated vehicles are broadly categorised into four groups: Transport operators (supermarkets and food distribution), commercial bodybuilders, leasing and rentals, and TRU Original Equipment manufacturers (OEM) and Dealers. Of the 139 businesses, 52 are transport operators, 23 are commercial bodybuilders, 44 are leasing and rental companies, while 20 are TRU-OEM businesses.

The survey was conducted through SurveyMonkey, and tailored questions were sent to various categories of stakeholders based on the nature of their business within the food cold chain system. For instance, questions sent to the bodybuilders differ from those sent to the TRUs equipment manufacturers. However, the questions centred on TRU numbers, composition (vans, trucks or trailers), fuel consumption, mileage, number of compartments, vehicle utilisation capacity, vehicle usage, renewable energy adoption, etc.

Table 1: Assumptions and boundary conditions for modelling

Boundary condition	Only the emissions related to the TRU were considered, while emissions associated with traction were excluded.
Other boundary conditions	• TRUs are predominantly powered with diesel, which was considered as the main fuel for the modelling. • The literature indicates that R404 is the predominantly used refrigerant. However, our survey suggests that R134a, R452A, R410A, R1270 and R744 also exist in small proportions. Hence, a common GWP is calculated as a function of the identified fractions. • Refrigerant leakages for various sizes of temperature-controlled vehicles are as indicated on HFC Outlook Model [13] and Francis et al. [14 • Electricity emission factor = 0.207 kgCO2e / kWh • The conversion factor for diesel is 2.63 kg CO2e per litre of diesel. • Vans are direct drive and only use a portion of fuel for the refrigeration system [15]. Previous empirical studies indicate this in the range of 14.5% to 25% of traction fuel [10,16]. Hence, 14.5% is assumed for vans.

3. Results and Discussion

3.1 UK food cold-chain and stakeholders

The food cold chain in the UK is complex and interrelated, involving production, packaging, processing, warehousing, wholesaling, and retailing with temperature-controlled transportation linking all stages. It also involves many active stakeholders (Figure 2), including vehicle manufacturers, bodybuilders, TRU original equipment manufacturers, retailers, food transport and distribution companies (Third Party logistics companies), food services enterprises, regulators, trade associations, etc. Typically, a temperature-controlled business approach bodybuilders with a vehicle needs and business requirements, e.g. size, temperature requirements, and compartmentalisation. The bodybuilder then advises on suitable chassis and TRU and then couples all the elements together and ensures the refrigeration box meets both business requirements and regulatory constraints, e.g., the choice of refrigerant and K-value box insulation system.

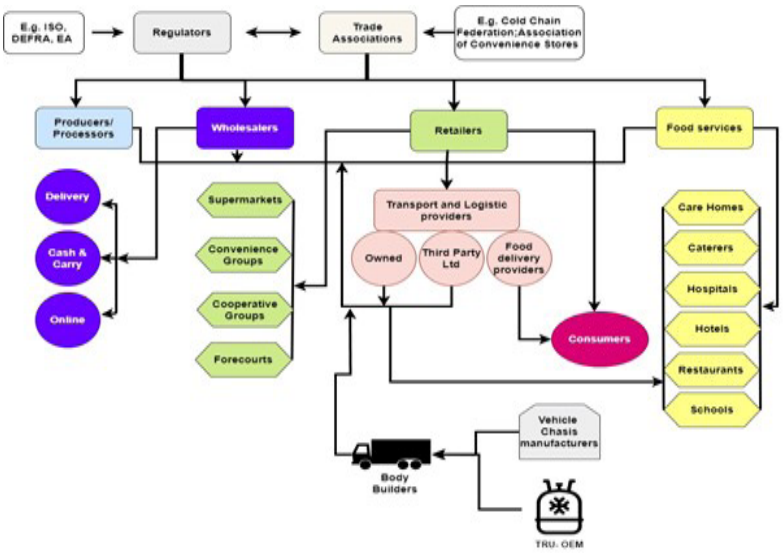

Figure 2: Temperature-controlled transport stakeholders.

3.2 Fleet size and compositions.

There were 26 responses from the survey, representing a response rate of 19% from the identified 139 stakeholders. Based on the fleet size, respondents control 36,181 temperature-controlled vehicles (TCV). This includes 863 TCV from bodybuilders, 7,952 from Lease and Rental service providers, 6,175 from TRU-OEM and 21,191 TCV from food distributors and retailers.

Our analysis of the fleet composition (Figure 3) from the survey indicated an estimated 49%, 10%, 37% and 3.9% for vans (LCV less than 3.5 tonnes gross weight), trucks (HGV greater than 3.5 tonnes but less than 18 tonnes gross weight), trailers (HGV greater than 18 tonnes gross weight), and e-cargo bike respectively. The Cold Chain Federation report of 2023 [9] suggested their 278 members, predominantly in the food storage and distribution sector, operate 62,730 TCV in the UK. This includes 21,561 trucks and 41,169 trailers but excludes TCVs of less than 3.5 tonnes. Therefore, given the fleet composition presented in Figure 3 and the fleet size of trucks and trailers (62,730 units of trucks and trailers) from Cold Chain Federation, we estimated temperature-controlled vehicles in the UK may be around 132,931. This includes 65,017 vans, 21,561 trucks, 41,169 trailers and 5,184 e-cargo bikes.

This was obtained using the following approaches:

Assuming we have X numbers of TCVs in the UK and the numbers of trucks and trailers are as indicated by Cold Chain Federation. If C, V, M and N represent numbers of cargo bike, vans, trucks, and trailers respectively in the UK; then,

C+V+M+N=X [1]

From CCF 2023

M+N=62,730 [2]; then equation [1] can be modified as in [3].

C+V+62,730=X [3]

Using our survey's percentage composition in Figure 3; (C = 0.039X and V = 0.4891X).

0.039X+0.4891X+62,730=X [4]

From equation 4, X is calculated to be 132,931.

However, the estimated 132,931 TCVs in the UK is considered a conservative figure due to the following reasons:

- CCF figure only accounts for its 278 members and there are temperature-controlled businesses in the UK that are not CCF members.
- There was 137.8 billion tonne kilometres cabotage (goods moved by a transport operator from another country) in the UK in 2020. It is possible that significant numbers of these vehicles are TCVs given that e.g. the UK imports 84% of fruits and 47% of vegetables. Hence, the actual numbers of TCV on the UK roads may be above our estimates [1].
- Logistics UK says their road members operate more than half of the UK's HGV fleet and more than one million vans and it is likely a substantial part of this is refrigerated vehicles.

Therefore, the survey result and other references found in the literature are used to obtain range for the refrigerated vehicles in the UK (Table 2) as detailed in Appendix I.

Table 2: Estimates of refrigerated vehicles in the UK

Vehicle type	Range
Vans	44,877 - 81,802
Trucks	21,561 - 39,301
Trailers	41,778 - 76,152
E-cargo	4,391 – 8,004
Total	112,608 – 205,260

Our analysis indicates penetration of e-cargo bikes on cold chain fleet composition, particularly for last-mile food delivery. This may be due to the known economic and environmental benefits of e-cargo bikes. Cargo bikes make journeys faster and more efficient, plus delivering improved air quality, which contributes to healthier and safer streets [17]. Leonardi et al. [18] assessed the impact of replacing diesel vans with electrical vans and cargo bikes in London and found a reduction of 55% in emitted CO_2 per parcel. The study also indicated a 20% decrease in total distance travelled because of the delivery system. Due to increased interest, a study for Transport for London estimates cargo bikes could replace up to 17 per cent of van kilometres in central London

by 2030 [17].

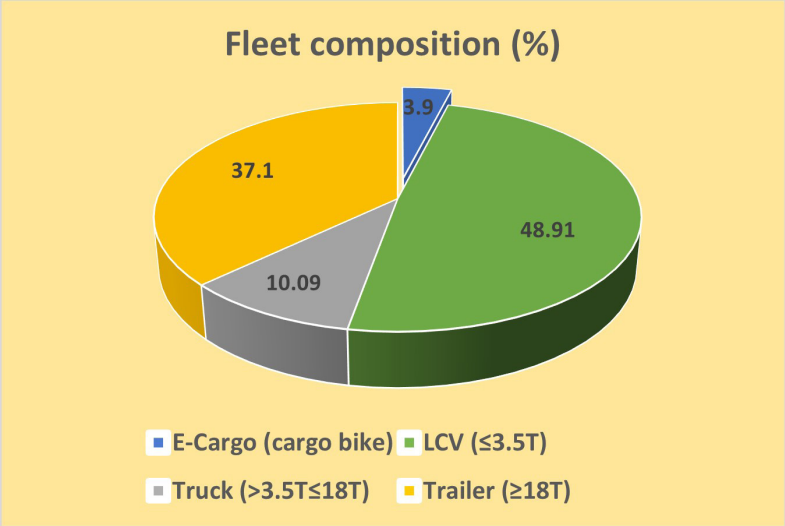

Figure 3: TRU percentage fleet composition

3.3 TRU Energy and Emissions

Energy consumption and emissions analysis are carried out using equations presented in Appendix II and as detailed in the references [16,17]. Data for modelling are as detailed in Table 3.

Table 3: Data input for TRU energy and emissions modelling.

Particular	Vans	Trucks	Trailer	Notes
Numbers of TRUs in the UK	44,877 – 81,802	21,561-39,301	41,778 -76,152	• Numbers of vehicles as estimated from survey and •Numbers of vehicles as estimated from survey, CCF data and literature. • •Details (capacity, refrigerant charge, leakage, etc.) of battery-driven compressor refrigeration units of the 5,184 E-cargo bikes are currently unknown. Thus, only energy-related emissions associated with E-cargo bikes are considered, while refrigerant emissions are not captured. Besides, considering the current numbers, the impact may be regarded as negligible. • The UK nationwide zero-emission vehicle accounts for 2.1% of all licensed vehicles in 2023[19]. Hence, about 1,365 vans representing 2.1% are modelled as electric vehicles with average energy consumption of 25.7 kWh/100km which is the average range for most delivery electric vans.
Annual TRUs running hours (hr/year)	2,167	2,299	2,299	• Results taken from survey responses are the annual running time of TRUs and not annual vehicle running hours.

Fuel consumption to run the refrigeration system (l/hr)	1.5	2.3	3.5	• Average TRU fuel consumption for trucks and trailers as indicated in literature [14][20][21] [15,16,22] and provided by a consultant managing over 10,000 vehicles in the UK. • Average TRU fuel consumption for vans as indicated in recent publication [20] where TRU fuel consumptions is 14.5% [14]. • Average energy consumption of cargo bikes is 55 miles/kWh, with a Transport for London report indicating an average distance of 90 km/rider/day [23].
Refrigerants	R404A, R452A R410a R134a R1270 + R744	R404A, R452A R410a R134a R1270 +R744	R404A, R452A R410a R134a R1270 + R744	• R404 is the predominantly used refrigerant in TRUs, accounting for between 80-90% [14,24]. • From the survey response, we estimate that the refrigerant usage may be around 83% for R404A, 14.81% for R134A, 1.79% for R452A, 0.36% for R410a and 0.04% natural refrigerant (R1270 + R744). • The GWP are 3922 (R404A), 2144 (R452A), 2088 (R410a),1430 (R134a), 2 (R1290) and 1 (R744) [25]. Based on the above percentage composition (refrigerant used) and GWP above, **3512.9** is the estimated average GWP and adopted for the refrigerant emissions evaluation.
Refrigerant Leakage	30%	11.4%	11.4%	• Refrigerant leakages of trucks and trailers are taken from the HFC Outlook Model [13]. • The refrigerant leakage rate of vans is taken from Francis et al. [11], which is empirical data of 327 delivery vans.
Refrigerant charge (kg)	2.0	2.5	5	Representative charge on most used TRUs as specified in literature[14,15,21,22,26].
Conversion factors	The conversion factor used for diesel is 2.63 kg CO_2e per litre of diesel and electricity 0.207 kgCO_2e/kWh.			

Depending on the number of vehicles, the annual energy consumption is as indicated in Table 4. The total energy consumption is estimated to be between 5.13 - 9.36 TWh. Previous studies by Foster et al. [12] and SKM [27] suggested indirect emissions from TRU between 1.02 and 1.20 MtCO_2e. Thus, putting TRU energy consumption within the UK between 4.64 TWh and 5.45 TWh using a carbon intensity of the grid of 0.22 kgCO_2e/kWh. However, this study was based on assumed 70,000 TRUs in the UK. As indicated in Table 4, trailers are the highest energy consumers, contributing around 71% to the UK's TRU energy demand while contributions from vans to energy use is around 4.5% despite its larger percentage of the total UK fleet.

Table 4: Annual energy consumption of TRUs by vehicle category.

Energy consumption	Energy consumption (TWh)
Vans	0.23 - 0.41
Trucks	1.24 - 2.27
Trailers	3.66 - 6.68
E-Cargo bike	0.0014 - 0.0025
UK Total	5.13 - 9.36

Our survey indicated that temperature-controlled fleet operators are increasingly purchasing lower/zero emissions vans and about 30% of their vans purchase in 2024 will be low/zero emissions vans. However,

only 2% of their predicted trailer purchase for 2024 will be low emissions. This may be because of challenges associated with low emissions Heavy Goods Vehicles within the UK. This includes high cost of ownership, high maintenance cost and lack of required infrastructure such as charging stations. The chief executive officers of three different temperature-controlled businesses stated the following:

- *"Over 95% of our sales this year are traditional engine driven systems. Our 12-volt and 400-volt systems are available and generating a lot of interest, the sales of commercial electric chassis are not coming through while grid infrastructure are not sufficient to meet the depot plug requirements of large fleets with a lot of vehicles".*
- *"We all want a better future, but it's very hard to currently justify and test equipment without some good support, I have 2 trailers on demo with Greenchill fridges which are battery powered but the cost is huge and there is no support from anyone, which is pushing me to consider selling them".*
- *"The initial cost of anything in relation to alternative fuels is a large investment in comparison with the current diesel option, with drivers' wages, cost of fuel, cost of equipment which have increased by over 20% in the last 18-24 months and high interest rates. I think there would need to be some radical changes and support from the government to decarbonise, the hauliers are already pushed to the limits with rising costs and little understanding from their customers in particular the supermarkets. I think there would need to be tax benefits, grants and many other initiatives to convince the market to change, there is a will from most to be green and look green to their customers and the consumer, but they cannot foot all the costs. If anything, I feel we will become less green because, due to current strains, people are running older equipment much longer, which is less efficient, increasing pollution".*

Therefore, more must be done to support the industry and meet the UK emissions reduction targets. The emissions associated with TRUs in the UK are presented in Table 5.

Table 5: Analysis of emissions by source and vehicle category

	Scope 1		Scope 2
	Fuel GHG Emissions ($MtCO_2e$/year)	**Refrigerants GHG Emissions ($MtCO_2e$/ year)**	**Electricity usage GHG Emissions (tCO_2e/year)**
E-cargo Bike	-	-	286.7 - 522.7
Vans	0.05 - 0.10	0.10 - 0.17	159.4 - 290.6
Trucks	0.30 - 0.55	0.02 - 0.04	-
Trailers	0.88 -1.61	0.08 - 0.15	-
UK Total	**1.23 - 2.26**	**0.20 - 0.36**	**446.1- 813.3**
	1.43 - 2.62		
	1.44 - 2.62		

Fuel used to power TRU contributes 86.1% of the emissions, while refrigerants-related emissions account for 13.9% of the total emissions, and 0.03% is contributed by electricity use. A previous study from Norwegian seafood put [28] fuel-related emissions between 63% and 87% while fuel use only accounts for around 62% of transport refrigeration emissions from another study [12].

4. Conclusion

Temperature-controlled vehicles in the UK are estimated to be around 158,934 ± 46,326; with e-cargo bikes

becoming prominent in last-mile food delivery. The energy demand and emissions associated with transport refrigeration in the UK are estimated to be 5.13 - 9.36TWh and 1.44 -2.62 $MtCO_2e$/year. An estimated 71% of TRU energy consumption is linked to trailers. Still, while uptake of low-emissions vans is increasing, the trailer is foot-dragging mainly due to challenges related to infrastructure and total costs of ownership. There is great uncertainty in the number of vehicles and therefore on respective emissions. Therefore, it is recommended that ATP registration should be made compulsory for all TRUs so that it can serve as database of refrigerated vehicles in the UK.

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Appendix I: Numbers of Refrigerated Vehicles in the UK

There are various figures reported for temperature-controlled vehicles in the UK. The figures are presented (Table 6) on numbers of refrigerated vehicles in the UK.

Table 6: Various references on the number of refrigerated vehicles in the UK

SN	Year	Numbers reported	References
1	2009	140,000	UK refrigerated road transport market. (iifiir.org)
2	2013	172,000	Special_Report_UK_Distribution.pdf (coldchainnews.com)
3	2014	84,000 growing at 10% per annum.	AIR0043 - Evidence on Action on air quality (parliament.uk)
4	2015	84,000 (vans - 50,000, trucks -16,000, trailers -18,000)	Liquid-Air-on-the-European-Highway.pdf (airqualitynews.com)
5	2021	100,000	Greening Refrigerated Transport - Financial and environmental impacts (cenex.co.uk)
6	Current calculation	132,931	CCF data + survey

The above references are normalised to 2023 using 25 years (1997 - 2022) average annual growing rate of LCV and HGV in the UK as detailed by the Department of Transport (Vehicle licensing statistics: 2022 - GOV.UK (www.gov.uk)). During this period, LCV grows at an annual rate of 4.04% while HGV grew at 0.72% per annum. The average is then used to obtain values in Table 7.

Table 7: Normalised estimates of refrigerated vehicles in the UK.

SN	Reference year	Ref year value	2023 Estimates
1	2009	140,000	195,132
2	2013	172,000	218,035
3	2014	84,000	198,000*
4	2015	84,000	104,649
2	2021	100,000	104,858
6	2023	This work	132,931

*reference mentioned 10% annual growth rate.

The 2023 estimates are then used to obtain a range for the temperature-controlled vehicles in the UK which is thought to be 158,934 ± 46,326, this range is based on the average and standard deviation presented in table 7. Of all references above, only reference 3 detailed vans, trucks and trailers as 50,000, 16,000 and 18,000 respectively. However, the 2023 estimates for trucks and trailers from the surveys carried out is 36,008 which is lower than 62,730 (trucks and trailers) reported by CCF which is a trade association representing around 278

temperature-controlled businesses in the UK. The proportion the UK temperature-controlled businesses who are members of CCF is unknown and it is likely that the numbers of refrigerated trucks and trailers in the UK is more than what is reported by the CCF. For instance, Logistics UK says their members operate more than half of the UK's HGV fleet and more than one million vans and it is likely a substantial part of this is refrigerated vehicles, however exact figures are unknown. Therefore, the estimated 158,934 ± 46,326 refrigerated vehicle is adopted, and percentage composition obtained from survey is used to obtain numbers of vans, trucks, and trailers. Hence, the breakdown on vehicle category is presented in Table 8.

Table 8: Estimates of refrigerated vehicles in the UK

Vehicle type	Range
Vans	44,877 - 81,802
Trucks	21,561- 39,301
Trailers	41,778 - 76,152
E-cargo	4,391 – 8,004
All	112,608 – 205,260

Appendix II

Annual total Emissions= Scope 1 (Fuel and Refrigerant Emissions)+

Scope 2 (Electricity Related Emissions) (5)

Annual fuel Emissions= (AFC x EM_{fuel}*)* (6)

Annual refrigerant Emissions= (C x GWP x ALR) (7)

Annual electricity Related Emissions=(AEC x $EM_{electricity}$*)*

Where:

AFC=Annual Fuel Consumption (L)

AEC=Annual Electricity Consumption (kWh)

$EM_{electricity}$*=Electricity Emission factor (*$\frac{kgCO_{2\text{-}eq}}{kWh}$*)*

EM_{fuel}*=Fuel Emission factor (*$\frac{KgCO_{2\text{-}eq}}{L}$*)*

C=Refrigerant Charge (kg)

GWP=Global Warming Potential ($\frac{KgCO_{2\text{-}eq}}{Kg\ refrigerant}$*)*

ALR=Annual Leakage Rate (% of norminal initial charge)

About the authors

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Dr Xinfang Wang is an Assistant Professor and the Group Leader of Resilient Systems for Energy and Cooling at the Birmingham Energy Institute in University of Birmingham. She has led several multi-million projects in the UK and EU on food cold chain, including Zero Emission Cold Chain (ZECC) and European food chain supply to reduce GHG emissions by 2050 (ENOUGH) . She also sits on the Research Committee for the UK Energy Research Centre (UKERC) and advises on the research strategy and priorities. She is the Equality, Diversity and Inclusion (EDI) Champion for UKERC.