Archetypal Insights to Decarbonise Heavy Goods Vehicle in Ireland

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Executive Summary

There are now a number of technologies and alternative low and zero carbon fuels available to help reduce emissions in the transport sector in Ireland. But in 2023 over 99% of heavy goods vehicles still used diesel which accounts for over 14% of all transport emissions.

This study provides an analysis of the decarbonisation potential for heavy goods vehicles (HGVs) in Ireland, using a mixed-methods approach that combines qualitative interviews of small to large fleet operators with quantitative data analysis to develop archetypal insights.

The vehicle archetypes primarily include heavy-duty diesel trucks used for medium to long-haul operations and operate mostly fully loaded, which contribute significantly to greenhouse gas emissions and local air pollution.

Many fleet operator participants are beginning to use sustainable HVO as a drop in fuel and Bio-CNG as an available alternative fuel, both growing in use but acknowledged as not the only or long term solution.

The geographic spread that HGVs travel underscores the importance of cross-border cooperation and harmonised policies to effectively decarbonise HGV operations, specifically with battery electric and hydrogen fuel cell electric HGVs in Northern Ireland, the UK & France.

Many operators support initiatives to introduce hydrogen trucks when it is available, mainly for heavy goods, over longer distances with fast refill requirements, sighting green hydrogen could significantly reduce transport emissions as well as stimulate the development of a green hydrogen market which could bring more work into the haulage industry.

Overall there was a message towards a need for a provision to be made for several elements of the decarbonisation infrastructures including vehicles, fuel stations, the fuel and even an urgent necessary mechanism (government/policy/regulatory support) needed to reduce risk and increase reliability of all the elements for early adopters.

Keywords: HGVs, Ireland, Decarbonisation

Contents

Background

The delivery of goods and services to consumers is critical to a country's economy. Land-based transport, especially heavy goods or commercial vehicles, has formed the backbone of the products supply system in most nations. In different nations, the term "heavy goods vehicle" (HGV) is defined differently (Zainuddin et al., 2023). It may differ based on the country's regulations, the license necessary to operate the vehicle, the car's weight, and registration. In Ireland, UK and other nations, large load-carrying vehicles are referred to as lorries, but in the United States and Australia, they are referred to as trucks (Cairney et al., 2011)

Road freight transit is important for European trade transporting 71.3% of all goods moved by land. HGVs are part of a logistical network that also includes inland waterways, sea, aviation, and rail transport. While each has advantages on its own, when joined, they constitute an integrated system. HGVs are also used by other forms of transportation to convey goods to and from depots, rail terminals, airports and ports.

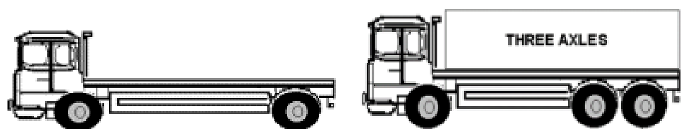
There are many classes of land vehicles, light duty, e.g. cars, medium duty, e.g. small buses and heavy duty, e.g. trucks, see Figure 1. Heavy Duty Vehicles (HDVs) can carry goods but also include construction vehicles, refuse vehicles, buses, tankers, etc. Heavy Goods Vehicle (HGV) or Large Goods Vehicle (LGV), is a type of heavy truck common in the European Union (EU). HGV drivers must have a specific driving license that permits them to drive trucks weighing more than 3.5 tons. Large vans, rigid trucks, and articulated vehicles are examples of HGVs.

HGVs are not only the most flexible, responsive, and cost-effective form of transport for the great majority of products and commodities items, but they are also critical to the operation of the wider, integrated European logistics and transportation system. The majority of our everyday requirements, including fresh food from the supermarket or corner store, newspapers and periodicals, electronics and appliances, apparel, and so on, rely on trucks / lorries at some point in the distribution chain. Many key public services, like waste collection, fire service and construction services, are supplied by them (Acea, 2023).

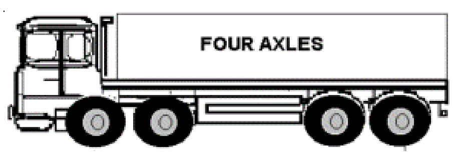
Ireland's economic development may be attributed to a steady flow of goods and services, which is facilitated by efficient international and domestic transportation networks. In 2021, Ireland's exports totalled €165.2 billion, while imports totalled €102.6 billion. The commodities distribution and logistics business is essential to the entire economy, employing approximately 103,000 people and generating €6.5 billion in gross value added. The road haulage business is crucial to Ireland's transport ecosystem, serving as both a frontline for exports and a backbone for imports. Ireland had 377,890 commercial goods vehicles in 2020, including 39,922 heavy duty vehicles.

In 2023 the Irish road haulage industry had 20,219 HGVs owned and operated by 3,791 licensed operators ranging from individuals to large enterprises. With about 14,224 heavy goods trucks (64%) licensed to conduct business internationally, with 5,955 HGVs, (36%) operate on a national scale. The majority of licensed haulage companies in Ireland are small, family-owned businesses with less than five HGVs.

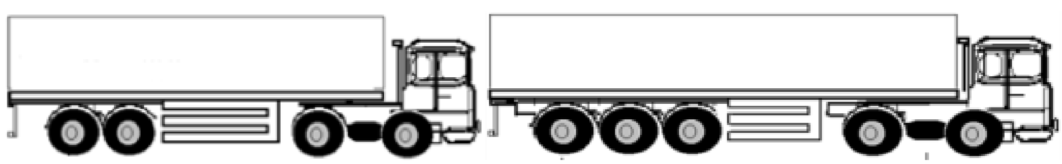
Rigid trucks 12 -18tonnes GVW: *Rigid 3 axles 26 tonnes GVW:*



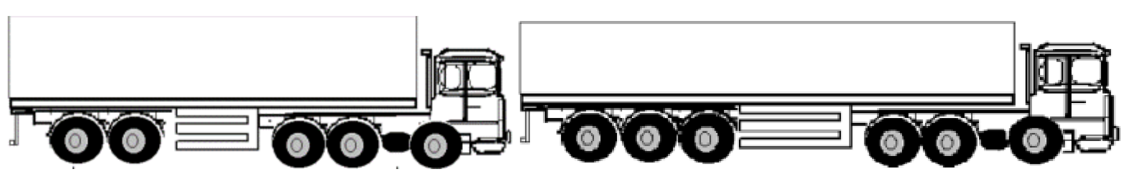
Rigid trucks >26 tonnes GVW (4+ axle):



Two axle articulated tractor units (Up to 40 tonnes GVW):



Three axle articulated tractor units (40-46 tonnes GVW):



2.9 - 3.5tonnes GVW <12tonnes GVW

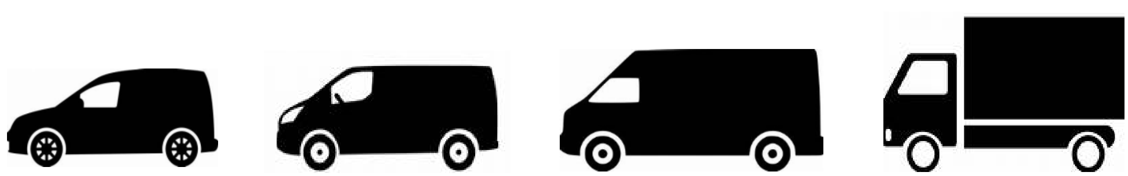


Figure 1 Vehicle classes [RSA 2023]

Historical Perspectives of HGVs in Ireland

HGVs are key corporate infrastructure, giving access to suppliers, transportation, and product manufacturing. Without them, companies would struggle. The history of HGVs reveals their economic importance since they allowed businesses to transport goods throughout the country and connect with suppliers. Understanding the history of HGVs can help us understand their role in our economy and the challenges they face.

Impact on Transportation Infrastructure, Society & Environment

There are occasions when very heavy equipment must be transported, and the resulting weight is several times more than the maximum load that the accompanying road segment was intended to handle. Such exceptionally heavy-load vehicles reduce the remaining service life of the road section and, in certain cases, render it useless and in need of repairs. In both circumstances, the requirement for repairs sooner than envisaged results in increased expenditures for local councils. This is required in places where the owner of the extremely heavy load truck pays for the vehicle passage to determine how much to charge the owner. In other places, where it is agreed that the cost of additional repairs is borne by the additional taxes paid by vehicle owners, such an estimate is required for road owners—for example, to the county or the state—to choose the route with the lowest expected additional cost of repairs [Ref].

Local roads can be destroyed by HGVs, with Arklow's local roadways an example (Raghnaill, 2023). Arklow councillors have criticised the damage of local roads by heavy goods trucks feeding nearby quarries, demanding that operators pay for repairs and the expedited completion of a long-delayed port road on the town's south side. The connected issues of getting worse roadways and the constant flow of heavy goods vehicles (HGVs) through the town have recently come under the spotlight, with the completion of Arklow's wastewater treatment plant on the horizon and a slew of expansive housing developments already in the works (Raghnaill, 2023). The Dublin Port Tunnel (DPT) and the HGV management policy have also been implemented in Dublin to mitigate the damage of HGV on road traffic and traffic pollution (Tang et al., 2017).

According to a study produced by the RSA in 2022 on the analysis of incidents involving heavy goods vehicles, HGVs account for 11% of vehicles involved in fatal crashes, totalling 137 HGVs (Bracken, 2022). Statistics by the RSA also show that of all HGVs that were involved in crashes, 3% of them (totalling 314) were categorised as serious injury crashes. It was also discovered that of the 134 fatal HGV crashes, a large proportion (49, 37%) happened between 12 and 4 pm, and a quarter (33, 25%) occurred on a Monday. According to the research, Cork and Dublin had the greatest number of fatal HGV crashes (14% and 12%, respectively). Rural roads had a higher proportion of fatal crashes involving HGVs (74%), as opposed to 60% of fatal accidents involving an HGV.

Despite making up just 5% of cars on EU roads, HDVs account for 25% of total road transport greenhouse gas emissions. The HDV sector accounted for more than 19% of total Irish land transport emissions in 2019 (Raghnaill, 2023).

HGVs make up a small percentage of all transport activities, but they contribute significantly (about 40%) to air pollution emissions, according to an assessment of the impact of the Dublin Port Tunnel and HGV management techniques (Tang et al., 2017). This goes to show that the impact of HGVs on transportation infrastructure is significant. Their effects include, among other things, vehicle accidents, damage to roads and bridges owing to their weight, road traffic congestion, emissions and pollution.

Infrastructure for clean transport, including trains and electric vehicles, should be prioritised in order to help the decarbonisation of motorised transportation and ease the deployment of alternative low emission fuel sources. This would encompass efforts being put into the production of alternative fuels (including hydrogen, bioethanol, biodiesel, hydrogenated vegetable oil (HVO) and biogas) in Ireland. The pathway to decarbonisation must therefore recognise the role of clean infrastructure and the need to change the present fuel economy from traditional fossil fuels to clean energy fuels towards decarbonising the majority of vehicles on Irish roads.

This study aims to improve understanding of the existing research and views on Heavy Goods Vehicles in Ireland, as well as the current condition of HGVs, policy and regulatory landscapes, and the challenges and opportunities of HGVs in Ireland.

Policy Developments Towards Alternative Fuels

The Irish government has implemented several regulations to lessen the impact of the haulage industry on the environment while also improving the sector's day-to-day operations, consequently encouraging economic growth. Ireland is committed to attaining carbon neutrality by 2050, but there are substantial hurdles ahead. The Irish government has implemented or is reviewing the following policies:

(I) **Ireland's Road Haulage Strategy 2022-2031:** The Irish Government announced the Road Haulage Strategy 2022-2031, which was executed in two stages of public engagement. The Road Freight Forum, composed of important stakeholders from the government, haulage and road freight sectors, will review the short-term initiatives' progress. The Government released the Road Haulage Strategy, outlining its approach to reducing transport emissions by 50% by 2030 in the challenging-to-decarbonise subsector. The strategy focuses on improving efficiency and reducing emissions through measures such as route optimisation, adoption of alternative fuels, and driver training programs. It also emphasises the importance of modernising the fleet with cleaner technologies to reduce environmental impact. The report mentioned the sector will expand its operations while concurrently reducing its emissions, admitting that HGVs are challenging to decarbonise but did not give adequate solutions to achieving this emissions reduction in the short or medium term (Department of Transport, 2022).

(II) **Trans-European Transport Network (TEN-T)**: The TEN-T policy is a crucial tool focused on the creation of a multimodal, well-thought-out, efficient, and cohesive transport infrastructure across the EU. The network consists of roadways that connect metropolitan nodes, inland and marine ports, airports, and terminals, as well as railroads, interior waterways, and short sea commerce routes. The network is in accordance with the Sustainable and Smart Mobility Strategy and the European Green Deal, to facilitate the shift to cleaner, greener, and smarter mobility in Europe. From 2024 through the Connecting Europe Facility (CEF) for Transport Programme - Alternative Fuels Infrastructure Facility (AFIF), there is €1Bn available to support the deployment of alternative fuels supply infrastructure along the Trans-European Network of Transport (TEN-T (European Commission, 2023).

(III) **Alternative Fuels Infrastructure Regulation (AFIR)**: This is one of the EU's frameworks to support the shift towards sustainable transport in Europe. It includes a mandatory target set for member states on charging and refuelling infrastructure development. Commencing in April 2024, the initiative is to encourage zero-emission passenger and freight road transport, enabling sustainable trade and engineering economic growth within the EU. Specifically, it is to generate economies of scale for producers and managers of infrastructure for alternative fuels. The regulation includes having HDV charging stations with a minimum 350kW output placed every 60 km along the TEN-T core network and every 100 km on the TEN-T comprehensive network starting in 2025. It also requires at least one hydrogen refuelling station (HRS) every 200km on the TEN-T Core network and at least one HRS in every urban node by the end of 2030 (European Commission, 2023).

(IV) **Alternatively-Fuelled Heavy-Duty Vehicle (AFHDV) purchase grant scheme (March 2021):** The Alternatively-Fuelled Heavy Duty Vehicle (AFHDV) purchase grant scheme intends to shift Ireland's heavy-duty road transport sector to low- and zero-emission vehicle technology. The programme intends to hasten the decarbonisation of the heavy-duty transportation industry, which includes trucks, buses, and coaches. It also intends to normalise and demonstrate low and zero-emission heavy-duty vehicle technologies to businesses and society, as well as to speed the rollout of alternative fuel infrastructure and to reduce emissions, air pollutants, and vehicular noise pollution (Department of Transport, 2014).

(V) **Renewable Fuels for Transport Policy Statement**: The Renewable Fuels for Transport Policy Statement is aimed towards assisting Ireland in fulfilling its 2030 emission reduction target of 51% and supporting the country's commitment to reducing greenhouse gas emissions in the transport sector. The policy statement aims to promote the efficient use of bio-based products and energy recovery as a last resort, after all higher-value products and services have been exhausted. This will involve a shift towards non-crop fuels, stricter sustainability criteria for all renewable fuels, and the cascading use of bio-based products. It lays out the steps necessary to implement a crucial aspect of Ireland's Transport Sector Climate Action Plan, which would significantly reduce CO_2 emissions over the next ten years (Department of Transport, 2021).

(VI) **Low Emissions Vehicle Toll Incentive (LEVTI) (2020):** The 2018 Low Emissions Vehicle Toll Incentive (LEVTI) Scheme expired on December 31, 2023. This scheme, introduced in 2018 was a strategy introduced by the Department of Transport to incentivise and stimulate the electric vehicle market in Ireland by providing toll discounts for alternatively fuelled and electric vehicles. The program was made available for vehicle owners depending on vehicle types (e.g. BEV, PHEV, FCEV) and class of vehicles (i.e. passenger vehicles, LGV, SPSV and HDV). In accordance with the LEVTI, BEVs and PHEVs were eligible for toll discounts of 50% and 25%, respectively, up to an annual maximum of €500 for personal vehicles and €1,000 for goods or commercial vehicles. For off-peak travel on the M50, a higher incentive rate of 75% and 50%, respectively, was applicable for BEVs and PHEVs (E-Toll, 2023).

Current Status of HGVs in Ireland

According to the Central Statistics Office's (CSO) survey of registered goods vehicles, Ireland's national HGV fleet is ageing, with vehicles 10 years or older accounting for 45% of all vehicles. Replacing trucks with cleaner alternatives might dramatically cut freight emissions; but if this is not done, a huge cohort of HGVs may be confined to diesel for years to come. The majority of licensed transporters in Ireland are modest businesses, with an average of four trucks. However, more than half of Ireland's haulers operating on a domestic basis have only one HGV. Hire or incentive vehicles accounted for a greater share of road freight transport activities in 2019 than own-account vehicles. Commercial purposes, such as haulage companies or logistics firms made up 72% of total tonne-kilometers, compared to 28% for own-account automobiles. Both own account and hire or reward vehicles made far more national travels than foreign journeys (AIB, 2022).

91% of road freight activity that starts in Ireland ends up somewhere else in Ireland, with 6% bound for the UK and 3% intended for other nations. The UK accounts for 66% of international road freight transport activity originating in Ireland, whereas Ireland accounts for 62% of origins in the UK. Germany accounts for 9%, with France and the Netherlands each accounting for 8% (DOT, 2021).

Environmental Impact

According to the Sustainable Energy Authority of Ireland, the transport sector in Ireland is the greatest source of energy-related CO_2 emissions, accounting for nearly 40% of emissions in 2022. 23% of Ireland's total GHG emissions come from Road Vehicles "Significant freight activity of heavy goods vehicles (HGVs) account for 14% of the road transport emissions in Ireland". The COVID-19 pandemic had a substantial influence on transport energy demand, resulting in a 26% drop in 2020. However, by the middle of 2021, transport activity and energy consumption had mostly restored to pre-pandemic levels.

With 19% of carbon emissions from transport, the sector is the second largest contributor to GHG emissions in Ireland as of 2022. HGVs contribute a large percentage of these emissions. 99% of HGVs in Ireland are diesel-powered, and 45% of the national HGV fleet is more than ten years old (DfT 2021). The Irish government's Climate Act 2021, in line with the EU Green Deal, has a target of 42-50% reduction in transport-related emissions by 2030. The road transport industry emphasises alternative and cleaner energy fuels for all vehicles, intending to phase out the sale of Internal Combustion Engine (ICE) HGVs by 2040 (Gov.ie, 2021).

Fuelling HGVs with Alternative Power trains & Fuels

Low Carbon Fuels (LCFs) are fuels that can provide greenhouse gas (GHG) savings compared to fossil fuels on a life-cycle basis. Biofuels, are growing in interest for high mileage trucks due to their potential to reduce emissions by 85% compared to diesel. Trials have demonstrated the technological readiness of E-fuels; synthetic fuels generated using renewable energy sources; but these are not yet commercially viable due to high production costs and lack of policy support (Ruf et al., 2021). Synthetic low carbon liquid fuelled trucks operate similar to conventional ICE trucks in terms of range and refuelling times and are currently available and in operation across Europe.

- **Diesel (Fossil Fuel):** like many other countries, Ireland relies heavily on imported fossil fuels to meet its energy needs. Approximately 85.8% of Ireland's primary energy requirement comes from fossil fuels (SEAI, 2023). Diesel demand in Ireland has been substantial, especially for transportation purposes. Ireland's transportation energy demand continues to depend heavily on fossil fuels. In 2022, fossil fuels accounted for 93.9% of road transport energy demand, with 68.6% specifically attributed to fossil diesel (SEAI, 2023). Diesel has a higher energy density compared to gasoline, which means it provides more energy per litre or gallon, suitable for long-haul transportation. Also, diesel engines are generally more fuel-efficient than gasoline engines, resulting in better mileage. Diesel is commonly used in heavy-duty vehicles, such as trucks and buses, due to its torque and durability. However, diesel engines emit nitrogen oxides (NOx), particulate matter (PM), and other pollutants (TCD, 2016). These emissions contribute to air pollution and health issues. While diesel engines are more fuel-efficient, they still produce CO_2.

- **BioDiesel Mix (Fossil Fuel mix):** Biodiesel, a 1st generation renewable fuel, is derived directly from (sustainably grown) biological sources such as vegetable oils or animal fats. It is produced through a process called transesterification, which converts these raw materials into a liquid fuel similar to diesel. In Ireland, biodiesel is blended with regular diesel and constitutes approximately 7% of the fuel supply. Biodiesel's compatibility with existing diesel engines makes it a viable option for long-haul transportation and heavy goods vehicles (HGVs) however biodiesel tends to gel at low temperatures, affecting its flow properties that can stall engines (Cléirigh, 2022). While biodiesel emits fewer greenhouse gases during combustion compared to fossil diesel, it is not clean, it produces nitrogen oxides (NOx) and particulate matter, contributing majorly to air pollution.
- **HVO:** Hydrogenated Vegetable Oil (HVO) is a 2nd generation liquid biofuel derived from waste or used vegetable oils through hydrocracking or hydrogenation. The widespread availability of HVO refuelling stations is still limited in Ireland (Certa, 2023). HVO produces tailpipe emissions emit CO_2, nitrogen oxides (NOx), particulate matter (PM), and other pollutants similar to biodiesel, albeit in lower volumes compared to conventional diesel (Bortel et al., 2019) however on a life cycle the reduction of CO_2 compared to diesel is almost 70% (ForestMachine, 2023).
- **CNG (Fossil Fuel):** Compressed Natural Gas (CNG) primarily consists of fossil fuel methane (CH_4), which makes up about 90% to 95% of its composition. The remaining 5% to 10% includes other gases such as nitrogen, carbon dioxide, helium, or hydrogen sulfide. Unlike LPG (Liquefied Petroleum Gas), which is a liquid composed of propane and butane, CNG remains in a gaseous state and is stored under high pressure for use in vehicles and other applications (Dey, 2023). CNG is considered a cleaner alternative to diesel and gasoline because it emits lower carbon dioxide (CO_2) levels during combustion. However, a study by Dey, Caulfield, and Ghosh suggested that replacing the current bus fleet with Euro 6/EEV CNG buses could lead to an 8% increase in CO_2 emissions compared to diesel buses in Ireland. This increase is primarily due to the higher energy content of diesel fuel (Dey et al., 2017). In addition further emissions can come from CNG fugitive emissions in the process of filling and transporting the potent greenhouse gas.
- **Bio CNG:** Bio-CNG is a 2nd generation gaseous biofuel produced from organic waste, a potential sustainable option compared to fossil fuel CNG. It offers up to 57% savings in CO_2 emissions compared to conventional diesel vehicles. The challenge is the sustainable

and effective utilisation of Ireland's waste resources that do not affect food or biodiversity or land use change or push emissions onto agriculture (Dey et al., 2017).

- **Electric Road System (ERS):** ERS technology, a conductive overhead catenary system, has been tested on public roads in Europe and the US, providing sufficient power for large HGVs at highway speed. However, ERS-enabled articulated HGVs are not yet mass-produced. There are no operating ERS trials in the Ireland or the UK, but funding has been provided to examine its feasibility in England. ERS has a small battery requirement, allowing vehicles to be charged during operation, resulting in longer range and minimal recharge times. However, it is only suitable for long-range HGVs and has high infrastructure development costs, making it potentially uncompetitive with other options (Transport Scotland, 2022).
- **Diesel/Petrol EV Hybrid (Fossil Fuel mix):** Hybrids operate by burning fuel in their internal combustion engines, similar to traditional vehicles and a generator recharges the high-voltage battery from the engine. While the engine runs on fuel, the battery assists in improving drive performance and reducing emissions and fuel consumption. Hybrid EVs are mainly attributed with passenger cars but trucks and van are available but not popular. In Ireland, hybrid EV passenger cars are the most prevalent type of EV, accounting for 45.3% of all passenger EVs in 2021 (CSO, 2021). Plug in Hybrid EVs, on the other hand, offer additional flexibility. These have an internal combustion engine and an electric battery, but unlike hybrid EVs, they can be charged externally via an electric outlet. This feature allows plug in Hybrid EVs to provide a longer electric-only range (Hayes, 2024). However, they still rely on petrol or diesel for longer trips, resulting in emissions from the exhaust pipe. Official tests indicate that plug in Hybrid passenger EVs emit an average of 44 grams of CO_2 per kilometre. However, an evaluation by pressure groups Transport and Environment and Greenpeace suggests that the actual emissions are closer to 120 grams of CO_2 per kilometre (Rowlatt, 2020). In essence, while HEVs and PHEVs address range anxiety and offer versatility, they do come with the trade-off of using fossil fuels and emitting pollutants.

- **Electric Vehicles**
  - **Battery Electric Vehicles – (electricity from grid):** Battery electric vehicles or BEVs produce no direct tailpipe emissions of pollutants or greenhouse gases but are as green as the electricity grid. These vehicles have a large battery (weighing several tonnes for a truck) and a large electric motor. The vehicles have ranges generally less than 500km (A scania EV has 350 km range at 40 tonnes load and 250 km range at 64 tonnes). The cost of an electricty grid connection to a charging point alone might range from £60,000 for an easily renovated site to £2 million for a poorly located/connected site. An ultra-rapid charge point (>150kW) can cost

between £20,000 and £60,000; therefore, a charge site for 10x 150kW chargers might cost between £260k and £2.5m.

- **Hydrogen Electric Vehicles**: FCEVs, or fuel cell electric vehicles, operate similar to a battery EV and motor but have a much smaller battery with a hydrogen fuel cell and a compressed hydrogen gas tank in addition. When used in a fuel cell, hydrogen combines with oxygen to produce electricity, heat, and water vapour, resulting in no direct tailpipe emissions of pollutants or greenhouse gases (Martins & Carton, 2023). FCEVs are slowly being mass-produced globally. FCEV are currently operating in Europe, with Hyundai delivering 18-tonne rigid FCET trucks in Switzerland in 2020. The technology is well understood in the UK, and with FCEVs already used in the bus sector and FCEV refuse trucks while FCEV gritters are being explored. Research and development into FCEV-Truck in the UK context is progressing, with a trial of Ballard Motive Solutions' 44t truck in Scotland receiving funding through the DfT's Zero Emission Road Freight Trials fund (Transport Scotland, 2022). FCETs are expected to become more readily available before BEV-Truck technology meets the required long ranges. They are suitable for large, long-haul vehicles, with an average range of 350-1250 km per fill/charge and a refuelling time of six to 40 minutes (JRC, 2021). Hydrogen infrastructure refuelling and hydrogen facility cost between £1m and £2m per station.
  - **Hydrogen (Green hydrogen):** Green hydrogen is hydrogen directly produced from renewable energy sources. Ireland's abundant renewable resources make it well-suited for green hydrogen production.
  - **Hydrogen (electricity from grid):** Hydrogen produced from grid electricity is only as green as the electricity grid similar to battery electric vehicles. As the electricity grid decarbonises with the growth of offshore wind energy clean electricity from the Irish grid may enable the production of 100% electricity & green hydrogen in Ireland using grid electricity passed on to decarbonise Irish transport systems across the country (Judge, 2023).
  - **Hydrogen E-Fuel:** Hydrogen can be combined with waste CO_2 to make high energy dense liquid fuel that can be 'dropped-in' as a direct replacement for existing diesel. E-Fuels have huge potential in applications that do not have alternative solutions to decarbonise, e.g. aviation. There is no commercially available E-Fuels used in HGVs to date.

Methodology

Understand Transport using Archetypes

Archetypes refer to a recurring pattern or model characterising specific transportation system aspects. These archetypes help classify regions based on their dominant modes of transport, e.g. such as walking cities, transit cities, bus cities, motorcycle cities, and car cities. Additionally, they inform urban transport planning scenarios, address relative accessibility, and consider the impact of different transport modes on a region. Archetypes are also used to understand behaviour patterns and match operational logistics and supply of goods with organisational behaviour of routes, and vehicle use, and also to get the emissions profile of vehicles.

Transport Archetype Review

A study by Navarro-Ligero and Valenzuela-Montes discusses the integration of scenario methods in transport planning, focusing on Light Rail Transit (LRT) systems. They introduce the "scenario archetype" concept to review planning documents and survey local planning actors, suggesting two main archetypes: robust and flexible. They highlighted the continuous transformation in urban transport planning, emphasising the need for foresight approaches to capture changes at different levels. They used the LRT system in Granada, Spain, as a case study to explore future-scenario methods. The study presents a methodological framework for generating scenario prototypes and archetypes, which encapsulate content-based and shape-based elements of the scenario process. This includes creating storylines and assessing scenarios through surveys of local actors. The authors propose that flexible and robust transport archetypes can provide alternative programmatic futures, aiding in the transformation of planning practices. Their research underscores the importance of adaptability and robustness in envisioning the future of urban transport (Navarro-Ligero & Valenzuela-Montes, 2022).

Another article by a group of experts presented a study on urban mobility which focused on identifying urban archetypes based on mobility-related characteristics of a city region. They employed principal component analysis and clustering methods to classify 96 cities into unique urban archetypes using publicly accessible data. The study identified nine distinct urban archetypes, ranging from Well-Functioning and Ancient Hybrid Cities in Europe to Paratransit and Traffic-Saturated Cities in the southern hemisphere. The findings suggest that future restrictions on private car usage will vary widely between urban archetypes, which has implications for urban planning and policy-making. Therefore, policymakers need to consider these differences when planning sustainable urban mobility solutions (Sascha von Behren et al., 2023).

An archetype approach for this study required primary data. This study employed a mixed-methods approach to gathering data, combining qualitative interviews and quantitative data analysis to explore the decarbonisation of heavy goods vehicles (HGVs) in Ireland. Data was collected via a semi-structured interview with participants who engaged with the request to be interviewed with the support of and collaborating with vehicle associations and groups. All haulage operators at any scale were targeted to participate. It is understood that larger operators are most likely to be the first movers in obtaining alternative fuelled vehicles. However the inputs from small and large operators for this study is important.

Questions within the survey are designed to collect information under four categories (see appendix for layout of questions):

1. Profile of respondents entails the very basic information; e.g., fleet size, depot locations, types of trucks in their fleet, etc

2. Operation of respondents involves the details of their operation e.g., annual mileage, annual fuel consumption, distance between refuelling, regions in which they operate, travel to, typical travel routes and delivery patterns, usual travel routes and operational patterns.
3. Challenges and opportunities in transitioning to lower-emission vehicles; Intentions for decarbonisation to ascertain the level of awareness towards decarbonisation and the changes it might entail e.g., impacts of carbon tax on their business, the future of their business. As well as the attitude towards acquiring low-emission vehicles e.g., what low emission vehicle (LEV) technology have they considered, do they have an LEV in their fleet, etc. Factors that would influence their decision in acquiring a LEV, the related barriers, and the support/incentives they would welcome.

A purposive sampling method was used to gather over 4% of fleet vehicles or almost 1% of the operators on the island of Ireland. Participants were chosen based on the following criteria:

- Ownership or management of a fleet of heavy goods vehicles.
- Active involvement in logistics and delivery operations.
- Willingness to participate in detailed interviews and provide vehicle data.

Each interview lasted approximately 45-60 minutes and was conducted either in person or via video conferencing, depending on the participant's preference. Information was collected, participant data was anonymised and data analysed through excel program for its simplicity and accessibility in constructing the questionnaire, disseminating the interviews, and compiling the responses.

Archetype Development

Based on the interview responses and vehicle data, fleet archetypes were developed to categorise the types of vehicles and their typical usage patterns. Archetypes were defined by factors such as:

- Vehicle size and type (e.g., light vs. heavy HGVs).
- Primary fuel type (diesel, electric, hybrid, hydrogen, biofuel, etc.).
- Typical travel routes (urban, rural, long-haul, short-haul).
- Weight & type of goods moved (heavy, light, parcel, etc)

Emissions Profiling

For each archetype, emissions profiles were calculated to understand the annual emissions. This involved estimating fuel consumption based on mileage and vehicle efficiency data. Applying emission factors for different fuel types to calculate CO_2, NOx, and particulate matter emissions. Emission factors were sourced from relevant environmental databases and government reports. The following formula was used to estimate annual CO2 emissions for each vehicle:

$$\text{Annual CO2 emissions (kg)} = \text{Annual mileage (km)} \times \text{Fuel consumption rate (L/km)} \times \text{Emission factor (kg } CO_2\text{/L)}$$

Interview transcripts were analysed using thematic analysis to identify common themes and insights regarding the challenges and opportunities for decarbonising HGVs. Descriptive statistics were used to summarise the vehicle data and emissions profiles. Comparative analysis was performed to highlight differences between archetypes and identify potential areas for emissions reduction.

Ethical approval was obtained from the relevant institutional review board. All participants provided informed consent, and data confidentiality was strictly maintained. Identifiable information was anonymised to protect participants' privacy.

Results & Analysis

This section presents the findings from the mixed-methods study on the decarbonisation of heavy goods vehicles (HGVs) in Ireland. The analysis encompasses various vehicle archetypes, annual kilometres travelled, emissions profiles, fleet sizes, and the relationship between these factors. Additionally, a GIS map visualises the typical travel routes, highlighting the extent of international journeys. The results are illustrated through several charts and graphs, each providing insights into different aspects of the data gathered.

Vehicle Archetypes Analysis

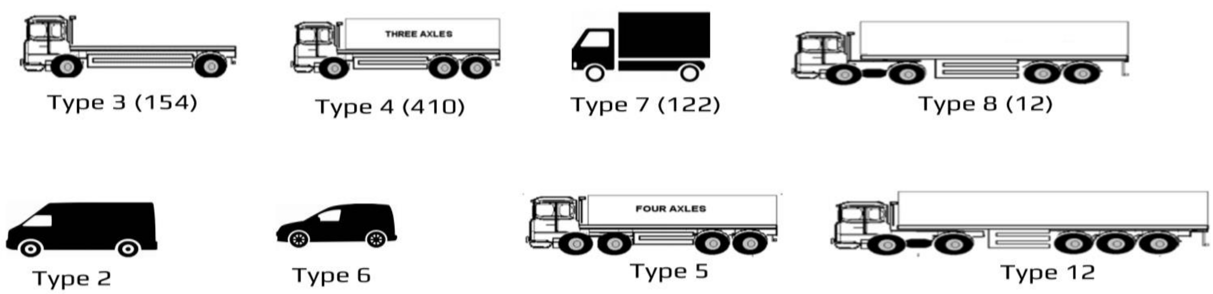


Figure 2 Main Vehicles identified in the study.

As shown in the chart, the most common vehicle archetypes in the study are types 3, 4, 7, and 8. Among these, Types 3 and 4 are particularly prevalent, indicating a high concentration of these vehicle configurations and operational patterns. These types predominantly include heavy-duty diesel trucks, which are commonly used for long-haul and high-mileage routes. Their prevalence highlights the significant impact these vehicles have on overall emissions and the importance of targeting them in decarbonisation efforts. Conversely, Types 6 and 12 are the least common archetypes in the study.

Annual Kilometres Travelled

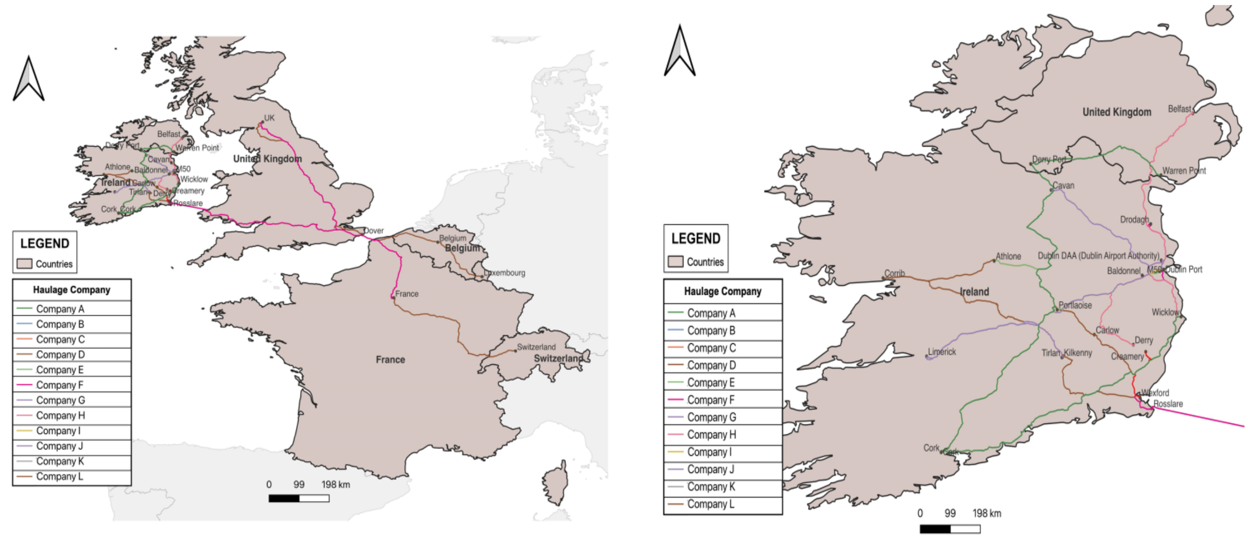


Figure 3 Representation of the usual travel routes of participants.

The analysis also categorises vehicles based on their typical travel routes, such as urban, rural, long-haul, and short-haul operations. This categorisation helps in understanding the operational context of each archetype and the specific challenges and opportunities for reducing emissions in different settings. Over 1.6million kms are drove annually by the participants of this study, with the map in Figure 3 providing a visual representation of the usual travel routes of the HGVs. This map includes routes extending beyond Ireland into other countries in Europe, illustrating the extensive reach of some operators. The map demonstrates that many HGVs operate on international routes, with some traveling as far as continental Europe. Most companies interviewed server the island of Ireland, with this data correlating well with CSO data of 91% of road freight activity that starts in Ireland ends up somewhere else in Ireland. Interestingly almost 50% of participants operate international fleets either from Ireland or just on the continent of Europe which is slightly higher than CSO data however the larger fleets that participated (figure 5) may have skewed the result. It was noted that the cost of getting to Europe was impactful with the boat through the UK being preferred travel at the time. This geographic spread underscores the importance of cross-border cooperation and harmonised policies in the effort to decarbonise HGVs.

Annual Kilometres Travelled

Company	Annual KKm
A	110
B	115
C	100
D	120
E	150
F	110
G	50
H	60
I	100
J	110
K	170
L	137

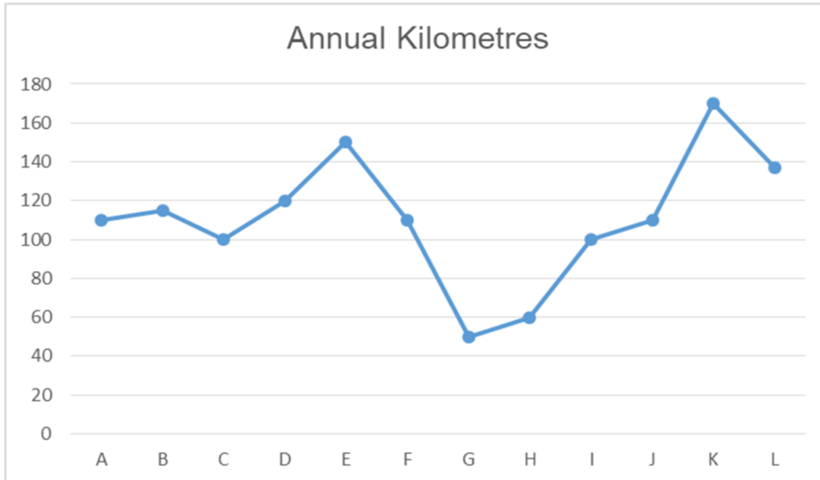


Figure 4 Annual kilometres travelled by the different vehicle operator participant.

This chart presents the analysis of annual kilometres travelled by the different vehicle operators. This data was crucial in understanding the operational scale and fuel consumption patterns of each archetype. This difference in travel distance has direct implications on fuel consumption and emissions, underscoring the importance of targeting high-mileage vehicles in decarbonisation efforts.

Fleet Size Distribution

This analysis examines the distribution of fleet sizes among the study participants. This chart provides insights into the scale of operations and the relative proportion of small versus large fleet operators.

The chart reveals a diverse range of fleet sizes, with both small and large operators represented. While larger fleets are more prevalent, there is a considerable number of small operators, emphasising the importance of inclusive strategies that address the needs and challenges of operators of all sizes.

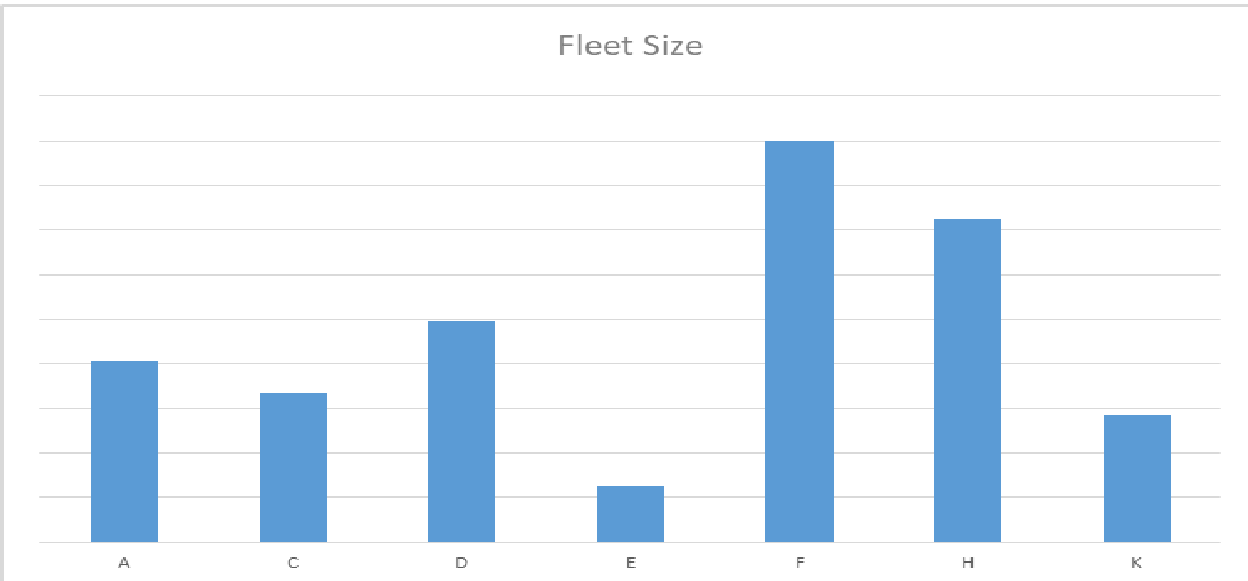


Figure 5 Distribution of fleet sizes among the study participants (actual size is removed for anonymity).

Goods Carried & Vehicle Load

Customer preference and what the vehicles carry affects the fuel performance and operational logistics. Ireland has a vibrant agricultural, food, pharmaceutical, building and technology industry and this is echoed in the products that participants carry day to day. Two thirds (2/3) of participants are mostly weight constrained day to day while operating their HGVs. Many operators mentioned that their smaller vehicles were more volume constrained than weight constrained and these may suit battery electric vehicles. Others described their heavy laden loads with no compromise for long charging or limited range and therefore are researching hydrogen as an alternative. The results are highlighted in Figure 6 by the types of goods carried across distances and possible usefullness for battery electric and hydrogen fuel cell electric HGV.

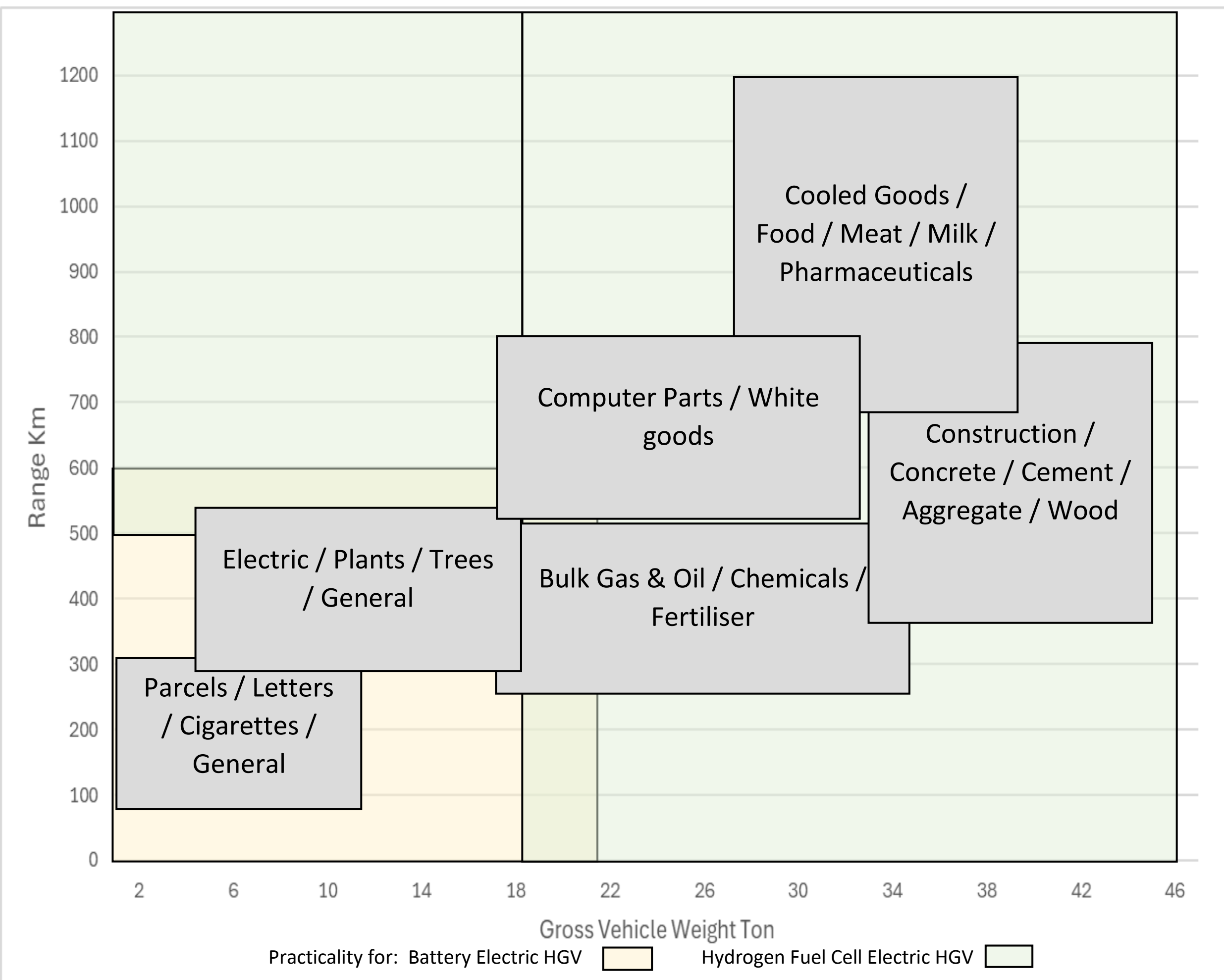


Figure 6 Types & weight of goods carried by participants across distances.

Annual Emissions Profile

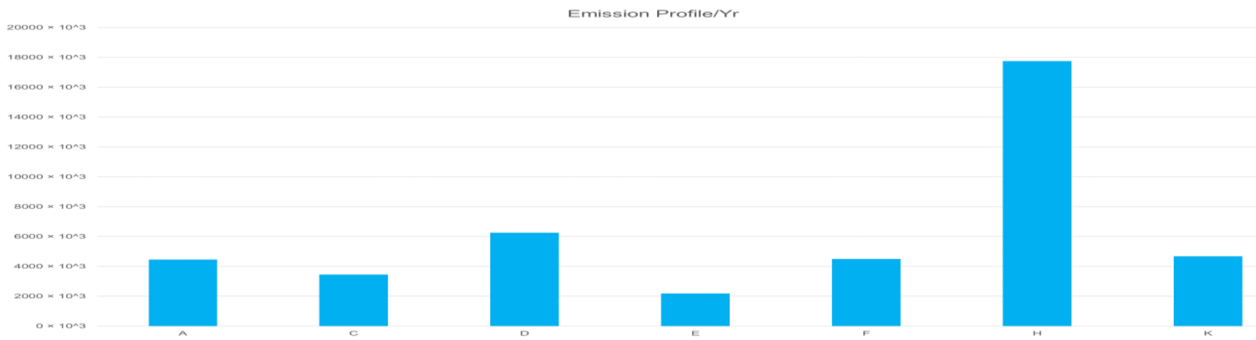


Figure 7 Annual emissions profiles for each vehicle operator participant.

This chart illustrates the annual emissions profiles for each vehicle operator. Emissions were calculated using the formula outlined in the methodology, taking into account fuel consumption rates and emission factors for different fuel types.

Emissions Profile vs Fleet Size vs Kilometres Travelled

The following chart explores the relationship between emissions profiles, fleet size, and annual kilometres travelled. This comparative analysis helps identify patterns and correlations that can inform targeted interventions.

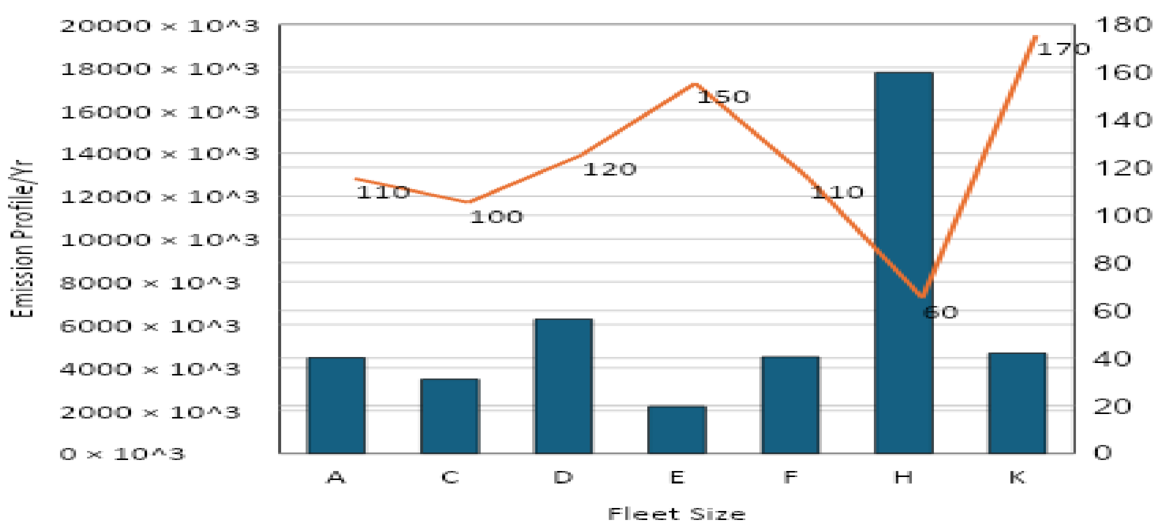


Figure 8 Emissions Profile vs Fleet Size vs Kilometres Travelled of participants.

The analysis indicates that larger fleets and those with higher annual mileage generally exhibit higher emissions profiles. However, there are variations within these groups, suggesting that operational practices and vehicle types play a significant role in determining emissions outcomes. This highlights the need for tailored approaches to decarbonisation that consider the specific characteristics of each fleet.

Challenges and opportunities in transitioning to lower-emission vehicles

HGV operators face many challenges to try and implement solutions. The following section presents a qualitative summary of discussions with participants towards decarbonisation of their fleets.

Infrastructure, Vehicles & Fuel Source

For many operators the easier option has been and many plan to transition to a similar fuel to diesel, e.g. HVO. Many participants discussed the benefits of going 100% HVO rather than blending, from an efficiency and a life cycle carbon savings perspective. Other participants mainly involved in the food industry felt that Bio-CNG (certified green and sustainable) was a logical step for them from a circular economy perspective and their trials and experience has been positive to date. A small number of operators already use battery EV trucks and there was a general sentiment from participants that these suit short trips and light goods. Hydrogen was mentioned by many as a potential green alternative fuel with quick refill and no compromised range but many envisioned that it is years away from being in their fleet due to fuel availability and cost.

Fuel supply was topical with all participants mentioning either certification and availability of HVO, too few fuelling stations for Bio-CNG or not enough powerful electric vehicle chargers. The non-existence of a hydrogen fuelling station network was an obvious challenge mentioned for hydrogen vehicle rollout, with hydrogen production supply seen as a lower challenge.

Infrastructure challenges also include vehicle availability and reliability as well as service and maintenance costs/agreements. There was discussions on trusting new entrants into the market especially around electric vehicles; battery and hydrogen. Small operators mentioned the risk for a small operator investing in a new technology was too much at this time.

No comments were gathered on electric road systems or hybrid vehicles and a few comments on hydrogen ICE as a transition to fuel cell vehicles. Some participants also felt that the potential use of E-fuels as a drop-in replacement for fossil fuel diesel, using existing infrastructure might be a solution if the availability and cost of E-fuels were actioned over the next decade.

Cost was discussed many times with all participants, with the emphasis on tight margins in the industry and rising cost of conventional diesel fuel as well as rising costs of conventional diesel vehicles becoming the norm, this having a sobering effect on thinking of costly alternative vehicles.

Overall there was a message towards a need for a provision to be made for several elements of the decarbonisation infrastructures including vehicles, fuel stations, the fuel and even an urgent necessary mechanism (government/policy/regulatory support) needed to reduce risk and increase reliability of all the elements for early adopters.

Conclusion

This study provides an analysis of the decarbonisation potential for heavy goods vehicles (HGVs) in Ireland, using a mixed-methods approach that combines qualitative interviews of small to large fleet operators with quantitative data analysis. By focusing on different vehicle archetypes, annual kilometres travelled, emissions profiles, fleet sizes, and typical travel routes, the study highlights key areas for intervention to reduce emissions in the transport sector.

The vehicle archetypes analysis revealed that Types 3, 4, 7, and 8 are the most common HGVs in the study, with Types 3 and 4 being particularly prevalent. These archetypes primarily include heavy-duty diesel trucks used for medium to long-haul operations and operate mostly fully loaded, which contribute significantly to greenhouse gas emissions and local pollution.

The geographic spread that HGVs travel underscores the importance of cross-border cooperation and harmonised policies to effectively decarbonise HGV operations, specifically with battery electric and hydrogen fuel cell electric HGVs in Northern Ireland, the UK & France.

Annual kilometres travelled varied significantly among the different archetypes, with heavy HGVs covering more distance annually compared to LGVs and existing low-emission vehicles (LEVs). This disparity in travel distances directly impacts fuel consumption and emissions, highlighting the need to target high-mileage vehicles for decarbonisation efforts.

The study also explored the industry's perspective on decarbonising their fleets, finding a positive interest in adopting drop in fuels as well as hydrogen technology when it is available, mainly for heavy goods, over longer distances with fast refill requirements. Many operators support initiatives to introduce hydrogen trucks, which could significantly reduce transport emissions as well as stimulate the development of a green hydrogen market which could bring more work into the haulage industry.

In conclusion, the decarbonisation of HGVs in Ireland presents a significant opportunity to reduce emissions & pollution in the transport sector. By focusing on high-emission vehicle archetypes, promoting and funding the adoption of zero & low-emission vehicles, and leveraging Ireland's renewable resources to develop a green fuel market, substantial progress can be made towards a more sustainable transport future. The findings of this study provide insights for policymakers and industry stakeholders to implement effective strategies for achieving these goals.

Recommendations

Based on the analysis of the decarbonisation potential for HGVs in Ireland, the following recommendations are proposed to effectively reduce emissions in the transport sector:

1. Target High-Emission Vehicle Archetypes:

- Focus efforts on decarbonising the most common and highest-emission vehicle archetypes, specifically Types 3 and 4, which are primarily heavy-duty, fully loaded diesel trucks used for medium and long-haul operations.
- Implement policies and incentives to encourage the replacement of these high-emission vehicles with low-emission alternatives.

2. Promote Adoption of Low-Emission Vehicles:

- Invest in & support the cost-effectiveness of low-emission vehicles making them a more viable option for operators in Ireland.

3. Develop a Green Hydrogen Market:

- Initiate projects to introduce hydrogen-fuelled trucks into the Irish market, supported by infrastructure development for hydrogen production and refuelling.
- Encourage public-private partnerships to drive investment in green hydrogen technologies and infrastructure.

4. Implement Inclusive Strategies for Fleet Operators:

- Design decarbonisation programs that cater to both large and small fleet operators, ensuring that smaller operators can also benefit from incentives and support.
- Provide technical assistance and training to help operators transition to low-emission technologies and practices.

5. Enhance Cross-Border Cooperation:

- Collaborate with the UK & European countries to harmonise policies and standards for HGV decarbonisation, facilitating smoother international operations.
- Develop joint initiatives and funding programs to support the deployment of green hydrogen infrastructure across borders (e.g. AFIR & TEN-T).

6. Support High-Mileage Vehicle Decarbonisation:

- Prioritise decarbonisation efforts for vehicles with high annual mileage, as these have a greater impact on overall emissions.
- Implement targeted measures such as dedicated lanes or zones for low-emission vehicles in high-traffic areas to encourage their use.

7. Expand Infrastructure for low-emission vehicles and Hydrogen:

- Invest in the development of a comprehensive network of electric vehicle charging stations and hydrogen refuelling stations across Ireland.
- Ensure that infrastructure is strategically located to support the most common travel routes and logistics hubs.

8. Foster Industry Engagement and Awareness:

- Conduct awareness campaigns and provide informational resources to educate fleet operators about the benefits and feasibility of transitioning to low-emission vehicles.
- Establish forums and platforms for industry stakeholders to share best practices and collaborate on decarbonisation initiatives.

9. Leverage Ireland's Renewable Resources:

- Utilise Ireland's abundant renewable energy resources to produce green electricity & hydrogen, positioning the country as a leader in sustainable energy production.
- Support the development of renewable energy projects that can supply the necessary power for green hydrogen production.

10. Monitor and Evaluate Progress:

- Establish a robust monitoring and evaluation framework to track the progress of decarbonisation initiatives and assess their impact on emissions reduction.
- Continuously update policies and strategies based on data and feedback to ensure their effectiveness and adaptability to changing circumstances.

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Acknowledgements:

We thanks Hydrogen Mobility Ireland & ERM UK for their advice and support for this study.

Appendix

General survey questions (during the interview process the questions were expanded to get deeper insights as necessary):

- Company Name:
- Location / Region:
- Fleet Size:
- Fleet age:
- Number of Drivers:
- Goods Transported (Typical):
- How much of your HGV fleet is made up of each of these vehicle types?
- What is the typical annual mileage for this vehicle type?
- How many days a year would it typically operate?
- Purchase trends?
- Drivers and vehicle usage?
- Operations volume-constrained? Weight constrained?
- Does your fleet perform any national routes?
- Does your fleet perform any international routes?
- Could you provide an example of a typical day for this type of vehicle?
- Could you provide an example of a typical extreme day?
- What are your current ambitions to decarbonise your fleet?
- Challenges in planning to decarbonise your fleet?
- What has worked to reducing your fleet carbon emissions?
- What factors (if any) have been the largest barrier so far to reducing your fleet carbon emissions?