THE FUTURE
OF TRANSPORT

PUBLISHED PROJECT REPORT PPR2002

Decarbonising UK Freight Transport: Understanding Freight Decarbonisation Investment Decisions

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Report details

Report prepared for:	ESPRC
Project/customer reference:	
Copyright:	© TRL Limited
Report date:	29/04/2021
Report status/version:	
Quality approval:	

Asleigh Wayne (Project Manager)		Marcus Jones (Technical Reviewer)	

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Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Reviewer

Document last saved on:	28/10/2022 11:28
Document last saved by:	Marina Garyfalou

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Abbreviations

AHP	Analytic Hierarchy Process
BAU	Business as Usual
BEIS	Department for Business, Energy, and Industrial Strategy
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CNG	Compressed Natural Gas
DC	Distribution Centre
DUKFT	Decarbonising UK Freight Transport
EV	Electric Vehicle
GHG	Greenhouse Gas emissions
GVW	Gross Vehicle Weight
HFO	Heavy Fuel Oil
HGV	Heavy Goods Vehicle
HVO	Hydro-treated Vegetable Oil
IMO	International Maritime Organisation
KERS	Kinetic Energy Recovery System
LEFT	Low Emission Freight and Logistics Trials
LNG	Liquified Natural Gas
MCA	Multi-Criteria Analysis
MCDM	Multi-Criteria Decision-Making
SOLAS	The International Convention for the Safety of Life at Sea
TRL	Transport Research Laboratory
WLC	Whole Life Cost
WTW	Well to Wheel

Executive Summary

While there is abundant research on low carbon technologies for freight, not much exists on the main drivers that steer the decision-making process to invest in cleaner fleets and recharging / refuelling infrastructure. This study has addressed this knowledge gap by consulting with organisations with freight transport investment responsibilities in the road, rail, maritime and public sectors. Such consultation has been essential to understand practical issues and enablers, in contrast to a theoretical analysis or technology-led approach.

Four online focus groups were held in February 2021, with 24 participants representing active stakeholders, each having vehicle fleet procurement responsibilities. The stakeholders were all UK-based except for one maritime company based in Cyprus with a global operation. Each focus group investigated one freight sector (with the number of participants in brackets): road (9), rail (6), maritime (3) or the public sector - local authorities managing their own vehicle fleets (6). We identified and ranked the key factors influencing the procurement of decarbonised fleets.

The main finding identified the key drivers, enablers or barriers associated with freight decarbonisation investment decisions and their relative importance. The key drivers across all sectors are illustrated in Figure 1.1.

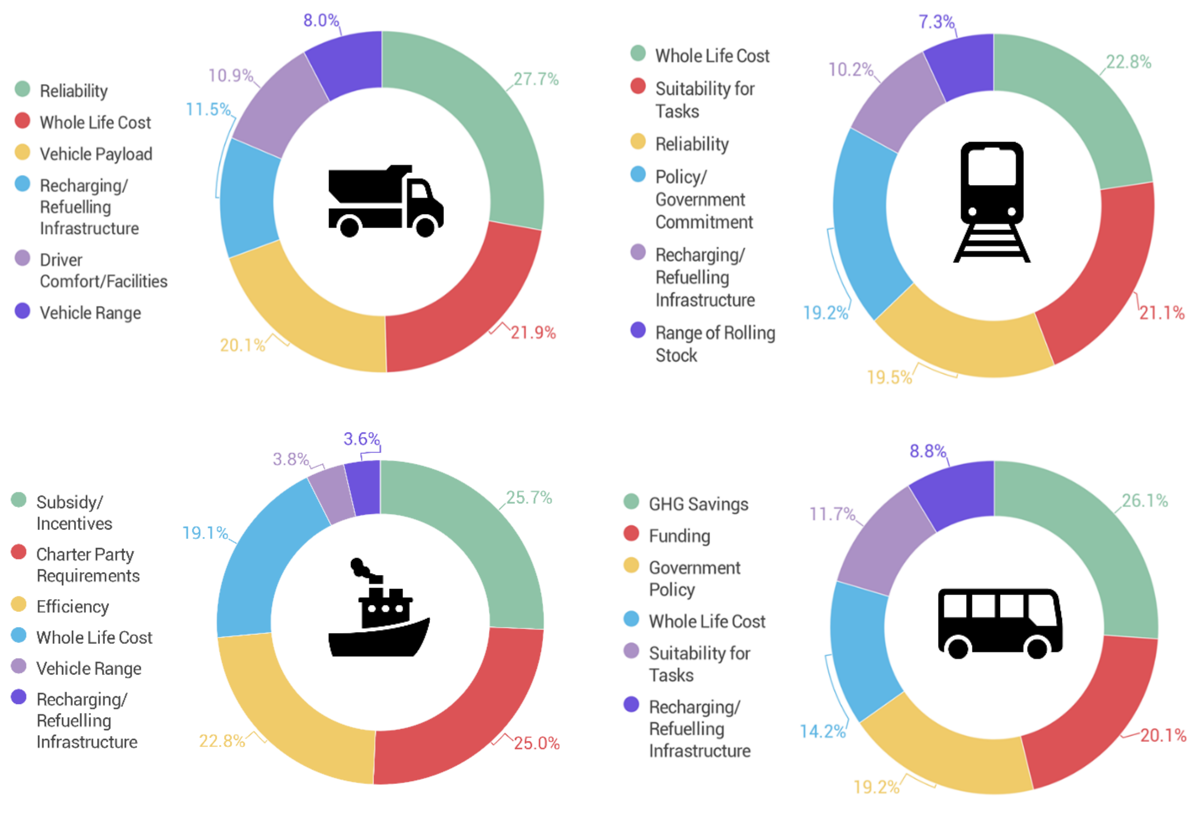


Figure 1.1 Key drivers and weightings attributed by road (top left), rail (top right), shipping (bottom left) and public authority freight groups

Whole life cost (WLC) was ranked highly by each sector and was needed to justify investments in vehicle fleets. This was considered easier to do for road vehicles as many low carbon options are commercially available; however, uncertainty about depreciation rates are a cause for concern for operators with low profit margins (e.g. 2%-3%). Currently, the cost of LNG is subsidised, making it a viable alternative to diesel for long-haul road freight operators. Electricity is relatively cheap making electric vehicles a viable proposition for small freight vehicles (e.g. vans), despite higher purchase costs. Calculating WLC for the rail sector was considered impossible at present due to the immaturity of the market. It is anticipated that any modifications to reduce carbon would have significant associated costs as the rail infrastructure itself needs to be updated alongside any new asset. Similarly, in the maritime group, the WLC of low carbon ships is not yet fully understood. Whilst some alternative fuels are under consideration, such as ammonia and LNG (Liquified Natural Gas), the cost of these fuels is significantly higher than the diesel or heavy fuel oil alternatives that are currently in use. Therefore, WLC may be a barrier to adoption of low carbon ships in the maritime freight sector.

Current lack of **recharging/refuelling infrastructure** in some places (e.g. more remote parts of the UK) and uncertainty about future provision were considered barriers to adopting low carbon assets at this stage. There appears to be a paradox where operators will not procure LNG vehicles until the infrastructure is in place, but fuel suppliers will not install infrastructure until there is proven demand for the supply. Where infrastructure is more widespread, low carbon vehicles are becoming more commonplace. The local authority participants felt they have a responsibility to aid in the deployment of infrastructure to support in the uptake of low carbon vehicles across all road transport. There was preference across the group for an infrastructure model that was accessible to all, such as a forecourt design for EV charging hubs as opposed to private charging facilities. This would enable wider uptake of electric vehicles both for private vehicle ownership and freight. To support hydrogen uptake in public sector fleets, local authorities are investing in the installation of their own refuelling infrastructure. For the rail sector, any adoption of low carbon rail assets is reliant on the infrastructure first being in place. Until there is certainty on what infrastructure will be deployed, the operators cannot make purchase decisions, but it is integral to the operator’s choices in the long term. Infrastructure requirements for the maritime freight sector are complicated by the industry’s international nature, meaning any vessel has to be compatible with ports around the world. As low carbon vessels are still in the early development phase, no solution to this barrier has yet been identified, but an added complexity is the variance in requirements across different types of freight cargo.

Vehicle range and payload were identified as key factors for the road, rail, and maritime freight sectors. With greater range, there is reduced time required for refuelling or recharging, and therefore less anxiety associated with lack of infrastructure. Similarly, the vehicle’s payload affects the efficiency of the entire operation. Long-haul operators in the road freight sector, often double shift vehicles, meaning that any downtime for refuelling reduces their operational efficiency. For this reason, electric vehicles were considered unsuitable, even if payload capacity was increased. It was recognised that the range capacity of low carbon vehicles has improved over the past five years although suitable options may be limited. The range and weight requirements for rail freight are considerable and, at present, can only be met by diesel trains. Infrastructure would need to be upgraded to support heavy axle loads to allow heavier freight trains access across the whole rail network. Range is an important requirement for the maritime sector as they need to transport goods long distances without the opportunity to refuel. Given the immaturity of the technology, it is not clear which alternative fuel will offer the range and payload capacity required, and therefore it is not known if this will be a barrier to uptake.

Subsidies or incentives were identified by the maritime freight operators as being necessary due to the current cost difference between alternative fuels and currently used fuels. The road freight operators stated that subsidies or incentives would increase the uptake of low carbon vehicles but did not consider this a key driver. The rail sector is at an early stage in the development of low carbon rail options (other than overhead electrification), and so the consideration for incentivising uptake may not be as applicable here. However, it was noted that what little funding the sector has for trials has come from private investors, rather than government. The public sector noted that government **funding** would be required to support the rollout of infrastructure and the uptake of low carbon vehicles.

Reliability was identified as the most important factor for the road freight group. They considered that low carbon freight vehicles are currently less reliable than their diesel comparators, though there was a suggestion that reliability was improving over time. The fact that many garages are not equipped to service alternatively fuelled vehicles was also a concern.

Efficiency was identified as a top priority for the maritime freight sector, where this was considered to mean the ability of the vessel to move freight at a speed which meets the time restrictions of the charterparty and has the payload capacity to move large amounts of freight in a single journey. Its absence as a top criterion in the other sectors could be due to the fact the fuel efficiency is a factor which feeds into the whole life cost calculation, rather than as a stand-alone criterion.

The vehicle **suitability** or **capability** was included as a priority for the public sector and rail groups and considered challenging to procure. The public sector group tend to operate mixed vehicle fleets, ranging from small vans to large refuse collection vehicles and with different needs depending on the area geography, infrastructure, congestion etc., therefore, there is no simple vehicle solution across different local authority areas or within one local authority fleet. With multiple factors under consideration the public sector participants did not feel equipped to understand which low carbon technology is suitable for which task. Greater understanding is needed of the advantages and disadvantages of adopting low carbon technologies to aid an informed choice. The rail freight group noted that no viable solution has emerged yet with the same capability as diesel. Electric powertrains are the most promising alternative, but the weight of batteries reduces payload. Hydrogen may be a future fuel option for rail but there is no route where this can be deployed yet, so it is too early to understand the capability.

Vehicle emissions were given as a key driver only by the public sector group. Many local authorities have ambitious targets to improve air quality, with measures including low emission or clean air zones. To set a good example, they also aim to decarbonise and lower emissions of their own vehicles and operations. The private sector is not under the same pressure to decarbonise their own operations and purchase decisions are motivated more by making profit in their businesses by operating efficiently.

While the key drivers for decarbonising UK freight were seen to vary between sectors, whole life cost was deemed very important across all the sectors (contributing over 20% to the procurement decision). This indicates that to decarbonise freight, the UK Government should implement policies that support the delivery of economies of scale that will translate to cost reductions until cleaner technologies reach cost parity with incumbent technologies. Governments worldwide have succeeded with policies promoting direct subsidies, grants, research and innovation credits or promoting green fleets procurement schemes. Mandates forcing fleets to decarbonise is another approach that has been used with success. This includes GHG emissions standards or phasing out fossil fuels. This is feasible but challenging for those organisations operating across international borders. However, unless the same rules bind international freight organisations, they could gain a competitive advantage that in a sector with small profit margins, could threaten the survival of local businesses.

1 Introduction

Decarbonising UK Freight Transport (DUKFT) is an EPSRC funded multidisciplinary research project focusing on understanding the opportunities to decarbonise freight transport across all transport sectors. The network created and projects funded comprises industry and academic partners.

In 2020, a small project funding was awarded to the University of Southampton and TRL for the project: *Understanding Freight Decarbonisation Investment Decisions.*

This project identified the current factors that influence procurement decision making for private and public sector stakeholders owning or controlling road, rail, and maritime freight fleets. Whilst research into low carbon technology is abundant, little research has been undertaken into the main drivers that steer the decision-making process of operators to invest in cleaner fleets and their infrastructure.

The objectives of the research were to:

1. Understand the factors that influence freight transport procurement decisions
2. Explore the differences between sectors (road, rail, shipping) and between stakeholders (private and public organisations)
3. Understand how decision factors have changed over time and are likely to change in the future
4. Model the relationships between these factors

In chapter 2, we included background information introducing the topic. This includes a literature review identifying low carbon technologies, available or under development, and the known drivers and barriers for the uptake of low carbon fleets. We describe the research methods in chapter 3. Four focus groups were analysed using thematic content analysis, whereby the qualitative data were examined to identify ideas and themes. In Chapter 4 we revealed the findings where we report the relative importance of procurement criteria for each type of group of stakeholder and sector. Finally, in chapter 5 we present the main conclusions.

2 Background

A brief background introduction on the policy landscape and the pathways towards decarbonisation for the road, rail and shipping freight sector and public sector fleets is presented in the following sections.

2.1 Road Freight

2.1.1 GHG emissions in the road freight industry

The 2008 Climate Change Act sets a target to reduce the UK's GHG emissions by at least 80% by 2050, relative to 1990 levels. Meeting climate change targets will require GHG emission reductions across all the economic sectors (DfT 2017). Domestic freight transport moved 189 billion tn-kms within the UK in 2017, of which 78% was by road (DfT 2018). Domestic and international freight activity is estimated to quadruple by 2050 (ICCT 2020). The road freight sector is an integral part of the UK economy, contributing £11.9 billion in 2015. More than 44,500 road freight enterprises in the road freight sector in 2015, employing around 248,000 individuals (DfT 2017).

Heavy goods vehicles (HGVs) (gross vehicle weight > 3.5 tonnes) account for a significant share of GHG emissions and represent an essential target for emissions control by adopting fuel efficiency and emissions-control technologies (ICCT 2020). HGVs account for around 16% of the UK's GHG emissions from domestic transport, despite making up just 5% of vehicle km (DfT 2017). HGVs mainly use fossil fuels, so there is a need to reduce their dependency on oil and its impact on climate change without limiting transport demand. The private sector can reduce GHG emissions when this does not negatively influence profitability; this is not always possible due to the high cost of some low carbon technologies (Velazquez Abad 2016).

HGV GHG emissions are projected to fall gradually to 2025 because of ongoing fuel efficiency and incremental logistics efficiency improvements. However, by 2025, rising HGV kms will outweigh those improvements in fuel efficiency, and emissions will eventually start to increase again under a business as usual (BAU) scenario. Continuing along with a BAU path would make it increasingly challenging to meet the road freight sector's climate change targets (DfT 2017).

The COVID-19 pandemic has illustrated the vital role the trucking industry plays. Although fuel costs have dropped, they are still a significant part of the operator's expense. Thus, the industry requires solutions that reduce fuel consumption to help it stay profitable (NACFE, 2020). A range of cost-effective technologies to improve HGVs fuel efficiency is readily available. Unfortunately, multiple barriers have stymied industry adoption of such technologies; these include a lack of data about the actual performance gains and operator confidence in the payback for investment (NACFE 2020).

2.1.2 Green procurement in the road freight industry

The UK Government has committed to supporting the road freight in implementing cost-effective GHG emissions reduction measures (DfT 2017). However, further steps will be needed to deliver a significant emissions reduction in line with climate change targets to establish the Emissions Reduction Plan.

Several existing policies and measures are already in place to support a reduction in GHG emissions from the road freight sector, alongside the efficiency improvements expected to come forward. A selection of measures is summarised below, some of them driven by the recent '10-point plan for green recovery' (HM Government, 2020):

- In 2017, sustainable biofuels in the UK were encouraged primarily through the Renewable Transport Fuel Obligation.
- A fuel duty differential is for road fuel gases, taxed at a lower rate than petrol and diesel.
- As a result of the expected rise of vehicle electrification, the Government is currently consulting on alternatives to compensate for tax loss from fuel duty.
- The Office for Zero-Emission Vehicles (OZEV) and Innovate UK announced in 2017 the winners of a £20m Low Emission Freight and Logistics Trial competition (LEFT), a project awarded to TRL who monitored and evaluated a range of low carbon technologies. The results were published in 2020.
- In 2021, DfT will announce the successful projects for a £20m programme to prepare the work for demonstrating battery, fuel cell and catenary powered HGVs (Zero Emission Road Freight Trials).
- OZEV will invest in deploying alternative and recharging infrastructure and the strategic road network from 2021 onwards.

2.1.3 Low carbon measures in road freight

While several technologies can reduce fuel consumption, it is often difficult for logistics companies to identify the most beneficial ones. The classification of low carbon technologies consists of the main areas of the vehicle body, powertrain, and fuel technologies (Velazquez Abad 2016). There is considerable diversity within the road freight sector, which comprises a mix of vehicle configurations, vehicle weights, duty cycles and fleet sizes. These factors will determine the suitability and cost-effectiveness of available GHG emissions reduction measures. The diverse road freight sector means that there is no single industry-wide decarbonisation solution, and a range of interventions must be considered (DfT 2017). Low carbon technologies for heavy goods vehicles studies also depend on the logistics operations' geographical location, as the gradient is a relevant factor. Other criteria include vehicle design (frontal area, mass, aerodynamic drag), driving cycles and operational differences (Velazquez Abad 2016).

2.1.4 Fuel Considerations

Diesel powertrain technologies can still improve their efficiency, but they have a theoretical limit (Velazquez Abad 2016). Therefore, the most cost-effective measure to reduce GHG emissions is using biomass-derived fuels (biodiesel B100); however those will not eliminate tailpipe air quality emissions. Renewable diesel fuel (hydrogenation-derived renewable diesel) and biodiesel are well developed, commercially available, and can be used in Euro 6 fleets. They offer an overall GHG reduction of about 80% relative to petroleum-derived diesel (Velazquez Abad 2016). Still, the importance of sustainability in the supply of biofuels, so that their increased use doesn't drive deforestation must be acknowledged.

While switching from diesel to gaseous fuels, such as biomethane, can reduce air quality pollutants, tailpipe emission of unburned methane (methane slip) is a known issue for biomethane and can offset any GHG savings. s shown in LEFT and LEBS, the bigger problem is that gas powered engines use spark ignition so are less energy efficient than diesel, which in some cases led to an overall increase in CO2 if grid average rather than renewable fuel is used (LowCVP, TRL, 2020). Advanced methane catalysts are currently being developed and are expected to significantly reduce methane emissions (DfT 2017). However, to better capture LNG trucks' climate impact in the European CO_2 regulations, it would be necessary to account for direct methane and nitrogen oxide emissions at the vehicle level (Mottschall 2020). Furthermore, there is little potential for using climate-friendly liquified methane (biomethane, synthetic e-methane) in trucks as renewable methane from low-carbon feedstocks is limited. In addition, there is intense competition for biomethane from other sectors (Mottschall 2020), such as heating.

TRL's work on fleets electrification (e.g. battery-electric, electric road systems) showed that they could reduce GHG emissions by over 95% with zero tailpipe emissions when combined with renewable pathways. In the longer term, 'on the road' charging through Direct Wireless Power Transfer or Overhead Wired Power Transfer may provide a viable option for powering heavier HGVs; however, this could be an expensive solution beyond their implementation in the strategic road network.

Concerning the hybridisation of commercial vehicles, the projected reduction in costs for plug-in hybrid-electric or battery electric vehicle battery packs will cause significant worldwide market growth in electrified light-duty vehicles by 2030 (TRB 2020). The regional haul is ideal for alternative-fuel vehicles, especially battery-electric trucks (NACFE 2020), but the lack of infrastructure to charge electric or alternative fuel trucks is a critical barrier to deployment (NACFE 2020). DfT ZERFT scheme and OZEV plans will tackle this challenge. In the UK, fossil-fuel hybrids will be phased out in 2030. However, there is scope for other types of hybrids, such as fuel cell range extenders. As a benefit of hydrogen fuel cells is that the vehicle uses an electrical drive train, so will be able to benefit from existing developments in battery vehicle technology.

Hydrogen represents one of three main options for low-carbon transport alongside biofuels and battery and catenary powered electric vehicles. Hydrogen avoids biofuels' land-use and air quality impacts and the limited range and long recharging times associated with EVs. However, electric vehicles are several years ahead of hydrogen in terms of maturity due to their economies of scale and readily available infrastructure (Staffell 2019). Trucks show considerable potential for fuel cell adoption as high energy requirements mean few low-emission alternatives exist (Staffell 2019). We have to acknowledge the lower system wide energy efficiency for hydrogen production (electrolysis plus fuel cells). There are benefits from being able to store energy as hydrogen, but should note that other storage technologies are also being developed that will compete with hydrogen, such as liquified air, pumped hydraulic systems, flow batteries etc.

Hydrogen can play a significant role alongside electricity in the low-carbon economy, with the versatility to provide industrial, heat, transport and power system services. It does not suffer the fundamental requirement for instantaneous supply-demand balancing. It enables complementary routes to deeper decarbonisation by providing low carbon flexibility and storage (Staffell 2019). Furthermore, hydrogen does not need to stress the current UK energy sector constraints. In the near future, it could be imported from where it can be produced from renewables at a lower cost (e.g. low and middle income countries). As with electric vehicles and unlike biofuels, fuel cell vehicles can tackle urban air quality problems by producing zero exhaust emissions (Staffell 2019).

2.1.5 Improved Freight Efficiency

A range of opportunities exists to improve energy efficiency and reduce GHG emissions in freight transportation. Influencing over some of these will require action and leadership by governments and the private sector (TRB 2020). Also, the development of freight transfer facilities near urban areas could increase the use of more agile, fuel-efficient, and less polluting vehicles for "last-mile" freight movements and facilitate the early adoption of autonomous vehicles. As such, the automated operation that enables truck platooning can save fuel and GHG emissions achieved through decreases in the drag of both trucks (TRB2020).

Using efficient driving techniques and in-cab monitoring technologies can deliver significant fuel savings and a corresponding reduction in GHG emissions from HGVs (DfT 2017). However, the critical barriers to the broader uptake of efficient driving training include upfront costs, lack of evidence of economic benefits, and challenges associated with sustaining initial benefits over time (DfT 2017).

As presented in **Table 2.1**, the factors that influence freight vehicle fuel economy can be divided into those intrinsic to the vehicle's design and those related to its environment or operating conditions. Various modes of operation can result in different fuel consumption rates.

Table 2.1 Factors influencing freight vehicle fuel economy

Existing technologies for the In-use fleet	Operational strategies
Aerodynamic improvements	Route and scheduling optimisation
Lower rolling resistance	Speed policies
Driveline efficiency improvements	Loading factors optimisation
Idling reduction technologies	Intermodal Strategies
Alternative fuels and additives (HVO, biomethane, cetane-enhancing additives)	Network optimisation and facility location optimisation
Electrification (batteries, fuel cells, electric road systems)	Training of drivers and development of incentivisation schemes
Mass reduction	Supply chain collaboration
Engine efficiency/thermal management	Vehicle platooning

The commercialisation and deployment of advanced technologies, fuels, and freight movement methods significantly different from those currently in use must start now to meet GHG decarbonisation standards, fuel policies and climate emergency targets.

2.1.6 The drivers for decarbonisation among logistics companies - key decision factors

As a result of Covid-19, the demand for freight transport rose because of the growth of home deliveries. Unless a shift towards more sustainable modes is successful, the most significant opportunity to reduce GHG emissions is decarbonising energy pathways. Some companies have already started declaring carbon-reduction targets, including several large third-party logistics providers (3PLs), whose decarbonisation programmes relate explicitly to logistics (Velazquez Abad 2016). McKinnon (2018) identifies the following factors influencing the willingness of commercial operators to implement green logistics:

- **Public Policy Measures** – Regulations and Incentives
- **Economic impact** - Positive net present value
- **Internal Motivation** - Company's reputation, consumer pressure
- **Technological Development and Accessibility** - Development of vehicles, technology, and alternative fuels; Easy access to facilities and technology

2.1.6.1 Public Policy Measures

The policy system is a driver for decarbonisation. For example, government regulation can encourage organisations to invest in low-carbon commercial fleets. In addition, the EU GHG emissions standards (or UK equivalent) and the introduction of low emission zones can help drive the decarbonisation agenda and are crucial to improving industry innovation and vehicle efficiency.

Regardless of whether measures would be cost-effective, logistics companies could adopt them given significant government intervention (Greening 2019). The sustainability efforts of logistics companies can also be influenced by whether they win or lose contracts. Therefore, decarbonisation could also be pulled by customers, corporate responsibility and environmental reporting initiatives. Thus, a firm's ability to prove its green credentials is an increasingly important factor in tenders (Gagan 2018).

Three broad classes of measures (taxation, emissions trading, and advisory programmes) can reduce the freight sector's carbon intensity in several ways. For example, road pricing can promote a modal shift to rail and water, improved vehicle loading, a rescheduling of freight deliveries into the evening and night, and greater use of low carbon vehicles (McKinnon 2018).

2.1.6.2 Economic impact

A company could adopt a decarbonisation measure if it were cost-effective for them to do so, in terms of positive Net Present Value (NPV) (Greening 2019). There is a close correlation between cutting carbon and reducing costs in the freight sector. Therefore, most measures designed to improve the efficiency of freight transport will also yield carbon savings. As most of these measures involve cutting fuel consumption, uncertainty around oil price volatility impacts payback periods and difficult procurement decision-making despite operational savings. However, not all low carbon and net-zero technologies are cost-efficient.

2.1.6.3 Internal Motivation

A company's corporate and social responsibility has proven to be one of the leading drivers in adopting low carbon emission measures in the supply chain. In addition, increased consumer awareness and pressure have forced shipping businesses to embrace zero-emission transportation methods (O'Brien 2019). Customer education also emerged as an essential key to improving the chances of decarbonisation success. Reducing GHG emissions has a positive reputational impact. Technological Development and Accessibility

Producing carbon disclosures can help organisations to get better financial conditions. Furthermore, access to a better range of low-carbon vehicles and government funding to support their growth eases the transition to cleaner operations (Gagan 2018). In addition, delivery and leasing firms need recharging and refuelling infrastructure in place, a mature supply chain, and a skilled workforce that can support the next zero-carbon fleets. There appears no universal set of criteria for the investment decision on low carbon or net-zero fleets, as no one solution fits all when assessing the technological landscape. Instead, a combination of technologies, policies, and strategies needs to work to decarbonise freight, so the sector's slim profit margins are not eroded further.

2.2 Public Sector

2.2.1 Policy context

Climate change is at the top of the national policy agenda. Local authorities have prioritised tackling air quality emissions due to their impact on human health; however, the policy landscape puts pressure on them to align strategies with UK Climate Change commitments.

The European Commission has set about reducing GHG emissions by 80-95% below 1990 levels by 2050. The EU aims to achieve a series of climate and energy targets by 2030, including reducing EU GHGs emissions by at least 55% below 1990 levels (EC, 2021). The EU CO_2 emission standards for HGVs state that, by 2025, GHG emissions must decrease by 15%, and by 30% by 2030, compared to a 2019/2020 baseline. Furthermore, 10% of all new HGVs bought by 2025 (up to 16t GVW) must emit zero tailpipe emissions, rising to 20% from 2030 (including larger vehicles). In alignment with EU policies, the Climate Change Act (2019) committed the UK government by law to reducing greenhouse gas emissions by at least 100% of 1990 levels by 2050 (UK, 2019). Although the UK is no longer in the EU, this Act remains in force, and, as a result, local authorities declare a climate emergency and set up net-zero transport decarbonisation plans.

The UK government recognises the environmental, social, and financial benefits of leaner, greener operations, estate management and procurement. The 2020 Greening Government Commitments programme has set out the UK government's commitments to delivering sustainable operations and procurement by 2020. In 2014-15, reductions in greenhouse gas emissions, waste, and water use in line with the Greening Government Commitments represented financial savings of £139 million to the government compared to the 2009-10 baseline year (DEFRA, 2016).

The Greening Government Commitments set out high-level targets for central government and its agencies to reduce operational consumption and waste and standards for transparent reporting on sustainable procurement and key sustainability areas (DEFRA, 2016). The commitments apply to central government departments' office and non-office estate and their Executive Agencies, Non-Ministerial Departments and executive Non-Departmental Public Bodies unless specifically exempted (DEFRA, 2016). Compared to a 2009-10 baseline, by 2019-20, the UK is committed to reducing GHG emissions by 32% from the real estate and UK business transport, with bespoke targets applying to each department, and reducing the number of domestic business flights taken by 30% (excluding MOD front line command flights) (DEFRA, 2016).

Decarbonisation of public sector fleets requires buy-in from local authorities; however, the support of central government is vital, as the most efficient solutions require national policies that will support economies of scale and cost-efficient fleets, alternative refuelling and recharging infrastructure deployment, alignment with the UK industrial strategy and invest in R&D.

2.2.2 Green procurement in the public sector

Green procurement in transport includes requirements relating to low- or zero-emission vehicles or technology in procurement processes. Governments can support the decarbonisation of transportation by using their purchasing power to choose assets, services and works with a lower environmental impact (ITF, 2020). Almost all OECD countries have developed strategies or policies to support green public procurement.

Until the early 1990s, purchasing policies and evaluation processes were dominated by price, quality, and delivery (Lindroos, 2015). Consideration is now put on how public procurement, subsidy and licensing regimes can increase the uptake of green technologies (DfT, 2019) and support the national industrial strategy. The main lever of green procurement is the contract award criteria that consider lower environmental impacts as critical factors.

EU green public procurement (GPP) criteria are designed to make it easier for public authorities to purchase goods, services and works with reduced environmental impacts. EU/EC has created and proposed a method of awarding points to reduce the GHG emissions approaches when purchasing new vehicles for the local fleet. The criteria include the technologies' performance and energy pathways (EC, 2019).

2.2.3 Public Sector Logistics Fleets

Freight fleets are typically privately owned and operated. However, most local authorities own, lease or contractually control small fleets of freight vehicles (from vans to small trucks) to move equipment or collect waste (e.g. from/to council sites). The public sector can lead by example by following green procurement programs, promoting public logistics facilities' deployment, and implementing policies that can influence the uptake of net zero logistics fleets.

Public sector fleet managers are required to meet several, often conflicting objectives, such as working towards meeting UK carbon budgets while keeping costs under already constrained budgets. Several technologies can make significant contributions in this direction (e.g. biomethane fleets and battery electric HGVs with hydrogen options already available in other European countries); however, their whole life cost is not expected to reach cost parity with incumbent diesel lorries until 2030. For this reason, central government support is needed.

2.2.4 Case Studies

Below we illustrate some of the decarbonisation initiatives implemented by different public sector organisations.

ECO Stars Fleet Recognition Scheme The scheme recognises best operational practices and guidance to improve fleets' efficiency, resulting in fuel savings for the operators and reductions in air quality and GHG emissions. ECO Stars has grown into a programme of 26 fleet schemes (for vans/trucks/buses/coaches) in the UK, a further 2 in Europe, and 5 UK taxi schemes. It effectively counts more than 600 ECO Stars members across the UK, operating around 20,000 vehicles. The Local Authorities fund the local schemes in England. In contrast, the funding comes from the Scottish Government's Air Quality Fund, shared between the Local Authorities in Scotland.

Transport for West Midlands (TfWM) Freight Strategy The approved West Midlands Freight Strategy and Implementation plan has provided TfWM with the tools to work together with businesses and a programme to deliver and share best practices in urban logistics management. It will provide an improved range of techniques to reduce emissions, noise, and congestion caused by goods vehicles and support the introduction of low or zero-emissions delivery systems (TfWM, 2020). Birmingham City Council has created a toolkit to support the development and implementation of Delivery and Servicing Plans by businesses and organisations operating in Birmingham. The toolkit aims to improve the quality of the environment around businesses by reducing congestion, collisions, and emissions (TfWM, 2020).

National Health Service (NHS) The key workstream areas of NHS broad commitments for embedding sustainability and reducing carbon emissions include the reduction of direct CO_2e emissions from NHS Supply Chain transport by 2.5% year on year and the reduction in business travel and related direct CO_2e emissions (NHS, 2017).

London Ambulance Service (LAS) LAS is frequently undertaking risk assessments and has a sustainable development management plan that takes account of UK Climate Projections 2018. In addition, the trust ensures that its obligations under the Climate Change Act and the Adaptation Reporting requirements are complied with (LAS, 2020).

2.3 Rail Freight

2.3.1 Background

There is a clear intent for UK rail to make a significant contribution towards the net-zero carbon target of the UK Government by 2050, in line with UK environmental policies and

Climate Change agreements. In the interim, rail must consider the UK Carbon Budgets and take appropriate decisions regarding the procurement and retrofitting of freight rolling stock and other relevant low carbon technologies. The Rail Industry Decarbonisation Taskforce report (2019) sets up the technical options to decarbonise rail, planning to remove diesel-only trains by 2040. The NIC (2019) highlights that 87% of the UK locomotives are powered by diesel.

Rail represents less than 2.5% of UK transport GHG emissions and less than 0.6% of all UK GHG emissions but with a carbon intensity 75% lower than road freight (Rail Industry Decarbonisation Taskforce, 2019). However, where freight trains operate through residential areas, they can represent an important source of air pollution that can force local authorities to designate those as air quality management areas and develop specific plans to mitigate emissions, as established in the EU Air Quality and Noise Emissions Directives.

In addition to emissions from trains, National Rail calculates that CO_2 emissions across its non-traction operational estate are around 300,000 tonnes per year. Its aspirational CO_2 emissions reduction target by the end of Network Rail's Control Period 5 (2014-2019) was 25% (Network Rail, 2019).

However, unless rail decarbonises, a modal shift towards zero tailpipe emissions modes such as road HGVs is likely (although this could increase congestion). Rail freight moves 9% of goods by weight. However, in the UK, international rail freight volumes represent just 4.5% of international goods by weight (NIC, 2019). It is estimated that there are around 850 freight locomotives in regular service (Rail Industry Decarbonisation Taskforce, 2019), most of them them being diesel. It is unclear who and how the required investments will be funded. However, before Network Rail's Control Period 7 (2024-2029), clarity is needed, and the decarbonisation strategy is aligned with the Road Investment Strategy (RIS3).

Many factors to consider when decarbonising rail freight include uncertainties about the policy environment, nationalisation of services, phasing out of fossil fuels, emissions standards, and the network's electrification. The Rail Safety and Standards Board RSSB (2020) T1160 report investigated options for decarbonising freight, including the procurement of new fleets and the refurbishment of older ones. One of the key decision factors for rail freight companies is the whole life cost (taking account of fuel costs); however, there are many factors involved in selecting locomotives, such as track access charges (which are weight-related), tractive effort, braking force, range, acceleration, route availability, safety, multiple-working capability, as well as finance availability, including green finance; subsidies, tax credits, etc.

EU decarbonisation targets require rail transport to introduce mitigation measures. The life expectancy of diesel locomotives is threatened by recent policy developments aiming to eliminate the sale of fossil fuels in the coming decades by several countries worldwide. The Netherlands has pledged to halt the sale of petrol and diesel fuel from 2030 (VVD et al., 2017) and the UK (Defra and DfT, 2017) and France (Ministère de la Transition écologique et solidaire, 2017) from 2035 and 2040, respectively. Knock on effects from phasing out fossil petrol and diesel road vehicles will spill to rail, as fewer investment in the fossil fuels’ supply chain will be made. This trend means that diesel locomotives may experience fuel shortages and operational challenges before the end of their life cycle and increased fuel prices with the addition of carbon tax. This strengthens the prospects of electric locomotives (powered via catenaries and third rail), batteries or fuel cells.

2.3.2 Low carbon technologies for rail freight

Different low carbon technologies can be considered in rail freight (**Table 2.2**). Most freight locomotives run on diesel or bi-mode (electric/diesel); however, other technologies are being deployed or trialled across the UK that could, under certain circumstances, perform adequately on freight operations. These could include hydrogen fuel cells, electric batteries, biomethane and other bio and electro-fuels, and regenerative braking or reversible substations . RSSB has commissioned many studies on several different aspects of rail's energy system, such as biodiesel (T697), electrification (T633), energy storage (T779) and hydrogen (T531, S100, S159).

Table 2.2 Low carbon technologies suitable for trains. For more accurate results, duty cycles must be analysed. Adapted from Kober et al. (2018); Rail Industry Decarbonisation Taskforce (2019)

Powertrain & Storage Technologies	Cost	Impact of GHG Emissions
Electrification	£2-4 million/km (single track)	Zero tailpipe air quality and low WTW GHG emissions when using green electricity.
Traction improvements / Regenerative braking	Slight increase in investment costs	AC asynchronous motors with IGBT inverters improve efficiency and reduce GHG emissions. Regenerative braking reduces emissions by 30%.
Hybrid trains (tri-mode electric/diesel/battery)	Slightly lower costs than bi-mode trains	It can combine with regenerative braking reducing GHG emissions 25%.
Hydrogen and fuel cells	Capital costs 20% higher than diesel. TCO 10% lower.	Zero tailpipe air quality and low WTW GHG emissions when using green hydrogen.
Natural Gas (CNG/LNG) and biomethane	Higher capital costs but savings of €200k/year/locomotive	Reduction of 70% NOx and 30% GHG emissions (CNG). Very low WTW GHG emissions when using some biomethane pathways.
Reversible substations	€650k/DC bidirectional substation (Payback 10 years)	Savings can reach 40%, with 99% captured regenerative power.
Energy storage flywheels	Higher capital costs but lower lifetime costs	Modern ones can save 10-15% energy consumption (by providing regenerative braking) when installed on traditional rolling stock.
Supercapacitors	Payback between 2-5 years	Combined with regenerative braking savings of 30% in passenger trains with 50% peak power reduction.

2.3.3 GHG emissions and performance considerations

According to Network Rail (2016), electric trains caused 20-35% lower carbon emissions than diesel ones; however, the contribution of renewables to the UK energy mix has increased the differential considerably and will continue to do so in the years to come while we transition towards a near net-zero grid system, it is expected that by 2040 overhead electrification emissions will decrease by 75%.

At system level, trains powered by overhead catenaries are much more efficient than any other technology. However, due to the very high costs of electrifying the whole rail network (according to NIC (2019), around £2-4m per single track kilometre), hydrogen fuel cells could be a good alternative for rail freight in targeted operations with lower utilisation rates, yielding zero air quality tailpipe emissions, low WTW GHG emissions, high power, long ranges and short refuelling times. Fuel cell trains require deploying a hydrogen refuelling infrastructure on the rail network or in mobile refuelling stations, such as recently tendered by DB Energie GmbH (2020) and economies of scale in hydrogen and fuel cell production to become operationally feasible and economically competitive. Hoffrichter et al. (2012) found that hydrogen fuel cell trains reduced well-to-wheel (WTW) greenhouse gas (GHG) emissions by 19% compared with conventional diesel traction locomotives (when hydrogen was produced via steam methane reforming).

Recent results from Alstom indicate that even using hydrogen produced from steam methane reforming, GHG can be reduced by 45%. Other pathways to producing green hydrogen (such as electrolysis and biomass gasification) increase those savings. While investing in electric locomotives is cheaper than other powertrain technologies for train operators, it is the most expensive solution for the UK Government for routes with low traffic. Hydrogen trains could become a cost-efficient solution for some rail routes until the whole rail network is electrified or breakthroughs in new battery chemistries are achieved. Table 2.3 compares the mass and volume of the powertrain and energy pack of diesel, hydrogen and battery-powered locomotives and found that batteries result in a payload penalty.

Table 2.3 Gravimetric and volumetric requirements to perform freight operations by different traction energy sources. Adapted from: Rail Industry Decarbonisation Taskforce (2019)

Train Type	Diesel	Hydrogen	Battery
Freight (engine + fuel)	36.1 t	32 t	251.5 t
Freight (volume)	6.49 m^3	63.8 m^3	150.5 m^3

Electric locomotives are the only zero-emissions solution for UK rail at the point of use. When their energy is produced from renewable energy, their well-to-wheel footprint can also be minimal. Network Rail aimed to electrify 51% of the rail network by 2021 (RDG, 2016), from the current 42% (currently 80% of the passenger journeys per km use electric trains) (Rail Industry Decarbonisation Taskforce, 2019).

However, budget constraints led to the cancellation of the electrification plans for the several lines in the past few years (Cardiff and Swansea, Kettering, Nottingham and Sheffield, and between Windermere and Oxenholme); it is now assumed that by 2039 just 48-50% of the network will be electrified (NIC, 2019). For this reason, the idea of using hydrogen-powered trains on some UK routes is gaining momentum. Transport Secretary Chris Grayling saw hydrogen-powered trains as a priority for Britain's railways (Katwala, 2018). These trains can be competitive with diesel ones (Hydrogen Council, 2017). This situation repeats in other EU countries. For example, according to Alstom, under half of the rail network in Germany is electrified, and it would take 95 years at the current investment rate to complete the work. To overcome this challenge, 200 fuel cell propulsion systems will be deployed over the next ten years (Hydrogenics, 2016).

In the UK, Alstom and Eversholt are planning the conversion of a Class 321 passenger train from electric to fuel cell trains (Alstom, 2018). In Poland, hydrogen is considered a fuel for freight locomotives transporting coal. Initially, hydrogen will be produced as a by-product of the conversion of coal into coke (JSW, 2018). However, not much academic literature exists regarding the technical, operational and environmental performance of battery electric trains (also known as Independently Powered Electric Multiple-Unit), and the existing papers (Ellem et al., 2014; Shtang and Yaroslavtsev, 2016) focus on freight and shunting locomotives. However, commercial sources are more abundant. For example, a battery-driven Bombardier ElectroStar train entered a passenger operation on British railways in 2015 (Bombardier, 2015). Network Rail said that this would contribute to the company's goal of reducing its environmental impact, improving sustainability and reducing the cost of running the railway by 20% over the next five years (Nichols, 2015).

In 2017 CRRC Changchun Railway Vehicles (China) tested an electric inter-city trainset equipped with an onboard battery to use in non-electrified lines in Inner Mongolia that can reach up to 160 km/h (Railway Gazette, 2017b). Auckland recently agreed to purchase 17 battery-electric trains for off-wire operation (Railway Gazette, 2017a). According to Shtang and Yaroslavtsev (2016), with battery costs decreasing to $250/kWh and $150/kWh, battery-electric locomotives would become competitive compared to diesel and natural gas shunting locomotives, respectively. However, these locomotives have short ranges and long recharging times, negatively impacting operations by reducing utilisation rates. Electric trains powered by wires are more energy efficient; however, they are better suited for routes with high ridership. Hence, it is unlikely to be an option for freight unless driven by a strong passenger transport business case on the same route.

Average speed of trains and route distance play a determinant role in selecting technologies. For example, battery electric trains are adequate for strategic train category A, where distance is up to 75 mph, and routes are under 60 miles (currently operated by diesel multiple unit classes such as 150, 153, 155 etc.). Hydrogen fuel cell trains can meet the requirements of category B (example, classes 16X, 17X), where speeds and range are higher; 100 mph and 160 miles, respectively. For category C (speeds of 125+mph and route distances up to 500 miles), diesel powertrains still are the best option when electrification is feasible. Freight locomotives operate at low speeds, and therefore could perform satisfactorily with hydrogen fuel cell powertrains; however, as illustrated in **Table 2.3**, battery electric freight locomotives are almost 8 times heavier than hydrogen and more than doubling the volume due to the energy storage requirement, making battery electric freight locomotives unfeasible at the moment. If the Government phases out red diesel in rail the cost increase of fuel (due to higher taxation) should improve the business case for zero emission technologies, shortening their payback periods.

Chapter 4 reveals the drivers for decarbonisation in rail freight, how these are evolving, their relative importance and the main barriers and opportunities to increase the uptake of lower carbon and net zero rolling stock and their recharging and refuelling infrastructure.

2.4 Maritime Freight

2.4.1 GHG emissions in the shipping freight industry

Maritime transport holds a critical role in international trade and the global economy. Marine freight carries around 80% of global trade by volume and over 70% by value (DfT, 2019). However, whereas shipping is considered one of the most efficient modes of transport, it still represents a substantial emissions source in terms of emissions per tonne-km (EMSA, 2019).

GHG emissions from international shipping amount to around 800 million tonnes of CO2e per year (DfT, 2015; T&E, 2018b), equal to 2.6% of all CO2 emissions related to energy use (GGF, 2020). Only in Europe, more than 138 million tonnes of CO2 were emitted in 2018, counting for over 3% of total EU CO2 emissions and more than 44 million tonnes of fuels consumed (EC, 2019). Shipping accounts for 95% of UK trade (DIT, 2019) and is considered one of the most carbon-efficient modes of transport (DfT, 2020), still, domestic shipping GHG emissions in the UK represent about 5% of the total (DfT, 2019; DfT, 2020).

Shipping emissions have grown by 70% since 1990, and shipping activity is projected to increase by between 50% and 250% by 2050 (IMO, 2014). The Initial International Maritime Organization (IMO) Strategy on reducing GHG from Ships commits globally to reducing emissions from shipping by at least 50% by 2050 compared to 2008 (IMO, 2018). There is also an intermediate target to reduce CO_2 emissions by 40% per transport work by 2030, compared to 2008 (IMO, 2018). But if no measures are taken, total shipping emissions could account for about 18% of worldwide greenhouse gas emissions by 2050 (EP, 2016; DfT, 2019; EC, 2019). Based on the fourth IMO GHG study (2020), total maritime GHG emissions, both international and domestic, and expressed in CO_2e, increased more than 9% between 2012 and 2018. Roughly 98% of these are CO_2 emissions.

In addition to greenhouse gases, shipping also emits air and water pollutants, such as sulphur dioxides, nitrogen oxides, and particulate matter, causing health and environmental issues. Moreover, shipping emissions in ports are also significant (GGF, 2020; DEEDS, 2020; ITF, 2018). These emissions have proven harmful to human health. For example, the Danish Centre for Energy, Environment, and Health (CEEH) estimated that around 50,000 premature deaths every year in Europe are due to ship emissions (Brandt, 2011). While research commissioned by Public Health England projects that, by 2035, £5.3 billion will be spent on health and social care costs due to air pollution (GOV.UK, 2018).

There are significant benefits from improving maritime vessels' operational and technical efficiency and adopting new zero-emissions technologies in the marine sector. Their combined potential could achieve the international target of 50% GHG reduction by 2050 (P. Balcombe, 2019; EEA, 2019; IIASA, 2018; T&E, 2018b). When combined with further operational efficiency measures, ship design efficiency requirements significantly impact emissions curbing. However, there are concerns about whether they will prove sufficient to decarbonise the sector or reduce its growing energy needs. The existent estimations are that with all the likely immediate measures adopted, energy demand for EU related shipping will still grow by 50% by 2050 over 2010 levels (CE, 2017; T&E, 2018b); therefore, action must be enforced immediately to mitigate this impact. Combined, operational changes, technology-based efficiency improvements, and low emissions energy pathways can potentially cut marine emissions by 67% from the current projection for 2050 (ICCT, 2020).

2.4.2 Green procurement in the shipping freight industry

The UK is focused on maritime decarbonisation innovation and is setting goals by 2025 and 2035 toward zero-emissions (DfT, 2019). The UK announced a maritime strategy toward zero-emission shipping, including short, medium- and long-term goals (DfT, 2020). Green procurement in shipping includes low- or zero-emission vessels, more efficient systems and technologies and supporting infrastructure. A previous call for evidence on non-tax incentives, encouraged the uptake of low carbon fuels, and unveiled a 'Greening Finance/Financing Green' maritime Initiative (DfT, 2019). In addition, in the Ten Point Plan published by the UK Government, a £20 million investment was allocated to the Clean Maritime Demonstration Programme (HM Government, 2020).

Newbuild capital costs for low- or zero-emission vessels are significantly higher than standard containers ships running on heavy fuel oil. Additional capital and operating costs depend on ship size and type. The use of modern alternative powertrains means a more considerable up-front investment but potentially lower operating costs due to reduced fuel costs, higher automation levels, and less maintenance. Contracts focusing on operating rather than upfront costs would automatically favour electric solutions (ITF, 2020).

Low- or zero-emission ships and their operation become cost-competitive with electricity tax exemptions (e.g. in Sweden) and a carbon price (ITF, 2020). Green contracts could also consider additional environmental benefits such as more sustainable wastewater management, non-toxicity of oils, additives or greases, antifouling, exclusion of certain hazardous substances, engines conforming with a higher emissions standards, or onshore power connection, etc. (ITF, 2020).

2.4.3 Low carbon measures in marine freight

Several technological and operational measures could reduce GHG shipping emissions, as presented in

Table 2.4 and

Table 2.5, respectively. The measures could contribute in some cases to creating an Energy Efficiency Existing Ship Index (EEXI).

Table 2.4 Main technological measures concerning potential CO_2 reduction (Bouman, 2017)

Technological Measures	Potential CO_2 reduction	Reference
Hull design		
Vessel size (Economy of scale, improved capacity utilisation)	4-83%	Lindstad, 2013
Hull shape (Dimensions & form optimisation)	2-30%	Lindstad, 2015
Lightweight materials (High strength steel, composite)	0.1-22%	Buhaug, 2009
Air lubrication (Hull air cavity lubrication)	1-15%	Buhaug, 2009
Resistance reduction devices (Other devices/retrofit to reduce resistance)	2-15%	EMEC, 2010
Ballast water reduction (Change in design to reduce size of ballast)	0-10%	Lindstad, 2015
Hull Coating (Distinct types of coating)	1-10%	Lindstad, 2015
Power & propulsion system		
Onboard power demand (On-board or auxiliary power demand e.g. lighting)	0.1-3%	Lindstad, 2015
Propulsion efficiency devices	1-25%	Lindstad, 2015
Hybrid power/propulsion (Hybrid electric auxiliary power and propulsion)	2-45%	Lindstad, 2015
Power system/machinery	1-35%	Buhaug, 2009

Technological Measures	Potential CO_2 reduction	Reference
(Incl. e.g. variable speed electric power generation)		
Waste heat recovery	1-20%	Lindstad, 2015

Table 2.5 Main operational measures concerning their CO_2 emissions reduction potential

Operational Measures	Potential CO_2 reduction	Reference
Speed optimisation **(Operational speed, slow steaming)**	1-60%	Psaraftis, 2013; Bouman, 2017
Loading factors / capacity utilization (At vessel and fleet-level / fleet management)	5-50%	Buhaug, 2009; Bouman, 2017
Voyage optimisation **(Advanced weather routing, route planning and voyage execution)**	0.1-48%	Buhaug, 2009; Bouman, 2017
Other operational measures (Trim/draft optimisation, Energy management, optimised maintenance)	1-10%	Buhaug, 2009; Bouman, 2017
Ship – port interface **(Ship scheduling)**	1%	ITF, 2018

Up until now, ships have been using mainly heavy fuel oil (HFO) and marine gas/diesel oils (MGO/MDO). Energy currently provided to ships by heavy fuels can, in the future, be replaced by alternative sources of energy that generate no or fewer 'tank-to-wave" GHG emissions (T&E, 2018b). The primary alternative fuels and measures are presented in **Table 2.6** concerning their potential emission reduction. Hybrid powertrains could also play a role.

Table 2.6 Alternative fuels and energy measures with their CO_2e emissions reduction potential for different type of vessels.

Energy Pathways		Potential CO_2e reduction	Reference
Lower-carbon fossil fuels	LPG, LNG, CNG, Methanol	5-30%	Lindstad, 2015; Calleya, 2014; Bouman, 2017

Energy Pathways		Potential CO_2e reduction	Reference
Carbon-neutral hydrocarbon fuels	Electro-fuels: electro-methane, electro-methanol, electro-diesel	Up to 100%	ITF, 2018
Carbon-neutral biofuels	Bioethanol from algae, vegetable, oil, sugar or starch	25-84%	Lindstad, 2015; Bouman, 2017
Zero-carbon fuels	Green hydrogen powering fuel cells - Electric Ships or ICE powertrains	up to 100%	ITF, 2018
	Green electricity - Battery ships (electric motor)	up to 100%	ITF, 2018
	Ammonia - Ammonia fuel-cells	2-20%	ITF, 2018
	Ammonia - Ammonia ICE	up to 100%	ITF, 2018
	Green hydrogen and ammonia - Dual fuel ICE	up to 100%	ITF, 2018
	Cold ironing (electricity from shore)	3-10%	Lindstad, 2015; Bouman, 2017
Renewable sources (auxiliary)	Wind power (kite, sails/wings)	1-50%	Lindstad, 2015; Bouman, 2017
	Solar panels on deck	0.2-12%	Lindstad, 2015; Bouman, 2017

Besides reducing shipping demand, low carbon energy pathways could arguably provide the most impactful measure to mitigate GHG emissions. Many factors can combine to yield the best solution. When investing in ships and retrofits, the total cost of ownership and efficiency improvements are essential decision criteria. Marine transportation is most sensitive to fuel cost, estimated at up to 80% of total expenditures (GGF, 2020). Other common barriers, as derived from the literature, include uncertainty over future energy prices, the stability of the regulatory environment, technology breakthroughs and payback, lack of access to low-cost financing, low-profit margins, lack of subsidies, and split incentives between owners and freight operators. Some of the key points found in the literature suggest that there is combination of solutions with no clear winner:

- LNG is reaching the mainstream and becoming affordable whilst effective in reducing emissions. But benefits are reduced by methane slip, which varies across engine types (P. Balcombe, 2019). LNG will likely be phased out to meet net-zero by 2050.
- Battery-electric propulsion appears to be the most efficient use of primary energy and the most energy-efficient technology pathway. However, the impact of batteries on vessel payload, range and operational constraints need to be factored in the procurement decision making (T&E, 2018b; Amplifier, 2020).

- Green hydrogen and green ammonia appear to be the second most efficient methods of energy provision when powering fuel cells, followed by ICE (T&E, 2018b; Amplifier, 2020). A study of a fleet operating between China and the United States corridors in 2015 found that almost 50% of the fleet's voyages could be completed when powered by hydrogen fuel cells with no amendments (X. Mao, 2020).
- A mix including battery-electric, liquid hydrogen organic carriers, and green ammonia would cause the least additional strain on the broader energy system. Synthetic fuels , on the other hand, would be the least optimal for the broader energy system and are extremely difficult to monitor and enforce (T&E, 2018b).
- Electro-fuels produced from renewables, although technically viable fuels and used in current shipping infrastructure and engines, can stress the energy system. They also have similar physical properties to their fossil incumbents, which would make difficult for port and flag states to control (T&E, 2018b).
- Wind assistance presents concerns from ship owners and operators with the technical risks involved and the hidden costs of the technology (Rehmatulla, 2017).
- Solar assistance appears sufficient only to augment the auxiliary power demands, while the erosion of solar panels, because of the water spray, causes a barrier (Calleya, 2014).
- Nuclear power has great decarbonising potential, but its widespread use is limited for safety and cost reasons (Calleya, 2014; T&E, 2018b) and it is typically used to provide baseline power, with not much surplus for other uses.
- Available biomass feedstocks are limited; hence it is more advisable to use them in a sector more challenging to decarbonise, such as biokerosene in aviation (T&E, 2018a). Moreover, bioethanol production technology from algae appears as a future technology with the potential to address the cost-effectiveness of renewable bioethanol biofuel (R. Bibi, 2017); however, it is unlikely that will be produced at large scale.

In conclusion, fossil fuels are likely to be phased out from shipping before 2050. A range of economically feasible short-term options exist, with newer, riskier alternatives available in the medium to long-term. However, given the long lifespan of a vessel of 30 to 35 years working life, the ultimate pathways will likely depend on the shipping industry's requirements regarding cost, efficiency, and safety (T&E, 2018b; P. Balcombe, 2019), among other factors identified in chapter 4.

As seen in the literature, the drivers for decarbonising freight in shipping include a range of other factors such as time horizons, the availability of alternatives, and the operations' nature. Factors such as total cost, safety, infrastructure limitations (e.g. alternative refuelling, recharging points or access to the power grid when mooring), operational performance, environmental impact, access to finance, policies and others weigh on the decision to purchase or retrofit lower carbon vessels. However, further research is needed to understand how these drivers vary across commodities, vessel characteristics and fleet ownership models.

3 Research Methods

Four focus groups were conducted. Each focus group focused on one sector: road, public sector, rail or maritime freight. Representatives from the sectors attended only the focus group relevant to them. The data collected were used to create Analytic Hierarchy Process (AHP) models for each sector. After the focus groups, individual interviews were held with the participants to evaluate their main drivers towards procuring decarbonisation assets. The focus group procedures and the description of the AHP method are presented in the following sections 3.1 and 3.2, and the findings follow in Chapter 4.

3.1 Focus Groups

3.1.1 Focus group participants and recruitment

Four focus groups were held via Microsoft Teams in February 2021. Twenty-four participants contributed to the groups, as shown in Table **3.1**. Each focus group lasted between 90 minutes and 2 hours.

Table 3.1. Focus group participants

Sector	Participant ID	Description of operator	Fleet characteristics
Road	Ro1	A transport and logistics operator with multiple depots across UK and Europe	Over 250 HGVs Involvement in some trials of natural gas-fuelled vehicles
	Ro2	A haulage company operating from a single depot	Approximately 120 HGVs Involvement in some trials of natural gas-fuelled vehicles
	Ro3	A large retail and distribution company with over 300 stores	Approximately 55 HGVs Involvement in some trials of natural gas-fuelled vehicles
	Ro4	A large retail supplier with over 700 depots across the UK	Over 500 HGVs, including some gas-fuelled vehicles and involved in a trial of energy-saving vehicle technology
	Ro5	A vehicle manufacturer	No direct fleet
	Ro6	A supplier of natural gas	Over 500 HGVs and articulated tankers Operates some gas-fuelled vehicles
	Ro7	Large independent logistics company with depots across UK	Over 250 HGVs, including some dual fuel and gas vehicles
	Ro8	Large building supplies company with hundreds of plants across	Over 200 operated HGVs plus over

Sector	Participant ID	Description of operator	Fleet characteristics
		UK	400 independently operated vehicles
	Ro9	A supplier of biodiesel	No direct fleet
Public Sector	PS1	Local authority representative for a large city	Approx. 1500 vehicles, mixed fleet including electric vans and electric and hydrogen buses
	PS2	Local authority representative for a large city	Over 1000 vehicles, mixed fleet including electric vans and hydrogen buses
	PS3	Representative of a combined regional transport authority	No direct fleet
	PS4	Local authority representative for a medium-sized city	Over 1000 vehicles, mixed fleet including electric vans
	PS5	Representative of a combined regional transport authority	No direct fleet
	PS6	Representative of a combined regional transport authority	No direct fleet
Rail	Ra1	Large rail freight operator	Mixed fleet, mostly diesel of different sizes. Some electric freight trains Involved in some trials of hydrogen
	Ra2	Representative for operators of rail freight	No direct fleet
	Ra3	Infrastructure owner	No direct fleet
	Ra4	Start-up company moving freight by electric rail	Electric trains for freight (not yet in operation)
	Ra5	Rolling-stock provider	Mostly passenger rail. Involved in some trials of hydrogen
	Ra6	Rolling stock provider	Approx. 80 trains. Involved in some trials of hydrogen and alternative traction modes
Maritime	M1	Cyprus based shipping company with a global operation	12 ships, investing in energy-saving technology for all ships
	M2	Vessel engineering company	No direct fleet
	M3	UK based shipping company which operates around northern Europe	34 ships, investing in energy-saving technology for 8 ships

Participants were targeted due to their responsibilities or knowledge of their organisation's decision-making regarding the procurement of low carbon freight investments. During a month, major operators of each sector and public bodies were identified, using key contacts of the project team and the Decarbonising UK Freight Transport Network+. The shipping sector proved to be the most difficult to reach out to, mainly because of the smaller number of contacts and its representatives' limited availability. More than 25 rail freight, 35 road freight and 15 shipping freight operators were contacted, along with 20 public bodies. The research period, which concurred with the Covid-19 pandemic and Brexit, appeared to be a challenging time for most of the operators and required additional effort to recruit enough high-calibre participants.

3.1.1.1 Focus group structure

Before each focus group, the participants received background information in an introductory pack with details of the study objectives and a review of evidence regarding freight decarbonisation investment alternatives available for road haulage, rail, shipping and public sector fleet operators.

Due to the COVID-19 pandemic, the focus groups were held virtually via Microsoft Teams. Two TRL facilitators led the groups. Mentimeter[1] software was used to gather responses to key questions; the responses were then used to aid discussions. Notes were taken, and the sessions recorded with participants' consent and later transcribed. An overview of the focus group structure is shown in **Table 3.2**.

Table 3.2. Focus group delivery structure

Section	Activity
Introduction to the research	
Participant introductions	
Identification of factors	Participants listed the key factors considered when investing in freight vehicles (standard and low carbon). This list prompted discussions about these factors, why they are important, and examples.
Ranking of factors	Participants ranked their top 5 factors – firstly for 'general' freight purchase decisions and then for 'low carbon' freight purchase decisions. The top 5 lists were discussed, with participants highlighting discrepancies between their personal top 5 and the combined top 5. In addition, any differences between the 'general' and 'low carbon' top 5 lists were

[1] https://www.mentimeter.com/

Section	Activity
	also discussed.
Changes over time	Participants discussed changes in their key criteria over the past 5 years and how they expected them to change over the next 5 years.
Barriers to low carbon uptake	Participants listed barriers which may prevent low carbon vehicle uptake. These were discussed, along with how the barriers may be overcome.
Introduction to AHP	Participants were given an overview of AHP and invited to contribute to the following research stage.

A copy of the topic guide followed in all focus groups is provided in 6Appendix A.

3.1.1.2 Focus group analysis

Focus groups were recorded via Microsoft Teams, and an automatic transcription tool was used to generate written transcripts of each meeting.

The transcripts were analysed using thematic content analysis, whereby the text was examined to identify recurring ideas and themes. A combination of deductive and inductive approaches was used, with some themes identified in advance (e.g. the importance of whole life costs and range) while others were derived from the data (e.g. changes in the importance of various factors over time).

The transcripts of the four focus groups were analysed independently from each other. The main ideas and themes were identified through thematic content analysis to become the main 'codes'. For each transcript, between six and nine main codes were identified. There was much duplication in codes between groups where priorities of different sectors are aligned, such as economic factors and policy and regulation requirements. Sub-categories were developed, driven by further consideration of the topics in the data. The codes and subcategories signposted relevant data for inclusion in this report and allowed oversight of where there are similarities and divergences between priorities of different freight industry sectors. Each subcategory is considered in turn in Section 4.1 of this report, and insights into participants' priorities are presented. How these subcategories align as criteria in the decision-making process for procuring low carbon assets is considered in Section 4.1.5.

3.2 Analytic Hierarchy Process (AHP)

3.2.1 Overview

Multi-Criteria Decision-Making, one of the decision-making theory methods, refers to making decisions in the presence of multiple and conflicting criteria (Lu, 2007) (Zopounidis, 2017). However, multi-Criteria Analysis (MCA) does not merely aggregate all the different factors and criteria. Instead, it handles them under the decision maker's system of priorities, values, objectives, and perceptions. As a result, it does not provide a unique solution, as this is contingent to the subjectivity of the decision maker.

Among the MCA methods considered, the Analytic Hierarchical Process (AHP) was chosen as we considered it essential to represent information in a way that allows owners or operators to compare the critical options. AHP enables modelling the problem, describing its qualitative parameters, and better understanding the sample's discreet choice model. In AHP, a set of evaluation criteria is chosen, and pairwise comparisons are used to assess each criterion's relative importance over another (Saaty, 1987). Psychologists argue that it is easier and more accurate to express opinions on only two alternatives than simultaneously on other options (Ishizaka, 2004; Saaty, 1986). AHP functions well in group decisions or a heterogeneous group of participants using the final analysis's geometric mean. This also mitigates the tendentiousness caused when all the judgments derive from only one expert (Saaty, 2005) (Aczel, 1983). There appear to be two points of importance in this decision-making; there is a level of uncertainty concerning each criterion's performance. Most criteria are behaviour or opinion-based. AHP can reduce complex decisions to head-to-head comparisons and then synthesize the results (Lu, 2007). This way, it can record both the objective and subjective aspects of the decision and translate the behavioural characteristics into quantitative data.

AHP is quite widely known for decision-making; however, inconsistencies may well occur when comparing the property with no established scale or measure (Saaty, 1987). AHP can handle the decision-maker's inconsistencies during the procedure (Harker, 1987; Forman, 1993). Still, a minor judgment inconsistency is always predicted since the human factor cannot be described by absolute stability (Saaty, 1980; Triantaphyllou, 1995). Therefore, a Inconsistency ratio should not exceed 10%. Researchers worldwide have used AHP in transport planning and policy projects (Berrittella, 2007).

3.2.2 Methodology

Every focus group's highest-ranked priorities were used to calculate weights and correlations further. The top 6 criteria of each focus group were used to create the AHP model. For the purpose of the research, an open-source AHP - OS software was used, made by Klaus D. Goepel (2018). The values used for the pairwise comparisons are their verbal equivalents are presented in **Table 3.3**. In **Table 3.4**, an indicative part of the final model created is presented. This specific one refers to the road freight sector analysis. Still, the logic behind it is the same for the other sectors. The AHP model was e-mailed to the participants, alongside guidance on approaching it. Following that, one-to-one interviews were held to review the ranking and discuss the inconsistency ratio, if needed.

Table 3.3 Description of the values used for the pairwise comparisons

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one element over another

Intensity of importance	Definition	Explanation
5	Strong Importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another
9	Extreme importance	The favouring of one element over another is of the highest possible order of affirmation
2,4,6,8 can be used to express intermediate values		

Table 3.4 Pairwise comparisons for the road freight sector

Criteria		more important?	Scale
A	**B**	**A or B**	**(1-9)**
Whole Life Cost	Vehicle Range		
	Vehicle Payload		
	Reliability		
	Recharging/Refuelling Infrastructure		
	Driver Comfort /Facilities		
Vehicle Range	Vehicle Payload		
	Reliability		
	Recharging/Refuelling Infrastructure		
	Driver Comfort /Facilities		
Vehicle Payload	Reliability		
	Recharging/Refuelling Infrastructure		
	Driver Comfort /Facilities		
Reliability	Recharging/Refuelling Infrastructure		
	Driver Comfort /Facilities		
Recharging/Refuelling Infrastructure	Driver Comfort /Facilities		

4 Findings

In this chapter, focus groups' findings and the results of the AHP method are presented. First, the findings are categorised by freight sector, followed by a combined overview.

4.1 Focus Groups

4.1.1 Road Freight

4.1.1.1 Whole life cost

All participants in the focus groups indicated that they calculate the whole life cost (WLC) of a new vehicle to justify the purchase and make investment decisions. The individuals representing large haulage firms indicated that a higher upfront cost of a vehicle is not necessarily a barrier if there is evidence to justify that there will be payback over the ownership period through savings in the cost of fuel afforded by improved fuel efficiency. For those that lease vehicles, upfront costs are minimal. Therefore, the higher upfront cost of a low or zero-emission vehicle would not be a significant barrier to a purchase decision. However, the depreciation rate of emerging vehicle technology is not yet fully understood, so it is difficult for operators to factor this into a WLC calculation.

> *"Being part of a global organisation, we're always challenged to look at the total cost of ownership...[which] is one of the criteria we have to fulfil before we're allowed to purchase vehicles or lease vehicles." –* ***Ro8***
>
> *"Depending on how you put your whole life costs together, fuel efficiency should be part of that." –* ***Ro3***

There is uncertainty over the WLC. It is hard for purchasers to justify moving to an alternatively fuelled low carbon technology because diesel is a cost-effective solution for operators in an industry with meagre profit margins where operators tend to avoid capital investment risks. Suppose there is a higher upfront cost for those buying, rather than leasing, the vehicles. In that case, the vehicle will need to be utilised as much as possible to shorten the payback period. New vehicle technologies are perceived as risky investment decisions, so operators prefer leasing rather than buying such vehicles.

> *"We trialled LNG; the cost of the trucks is significantly more, but we could save ten grand a year on the fuel. So, 50 grand a year on five trucks, five years, is an easy sell. There's nobody upstairs going to object to that." –* ***Ro4***
>
> *"But if you invest in a risky technology, you're far keener on leasing it. So, you're not carrying all the risk come to the end of the term." –* ***Ro4***

Whilst new technologies are emerging and some costs remain unknown, leasing companies will factor in an additional cost to account for the risk value, making the vehicles more expensive for operators to lease. In addition, low carbon vehicle manufacture is still a burgeoning industry. It does not benefit from the economies of scale, which allow diesel vehicles to be produced at a lower cost because low carbon vehicles are not being produced at the same scale. There is a feeling amongst the respondents that low carbon vehicles are at a premium for this reason. However, it is expected that prices will decrease as production increases over time. There is, however, a concern that additional costs will become apparent in time though, such as installing infrastructure.

> *"The cost of me installing my own refuelling station would be a massive barrier."* **- Ro6**

A smaller haulage company noted that the cost is the most important factor when competing to win contracts. Therefore, they will look to make savings down to the scale of pennies, as any additional costs would need to be passed on to the customer. Therefore, there is a reluctance to be an early investor in low carbon vehicles because there is much scope to lose the competitive edge financially.

> *"We measure in pennies a week over the fleet. We have to be competitive; the British economy is based around a competitive edge."* – **Ro2**
>
> *"Customers are unwilling to pay anything additional. So[…]we can't invest in a fleet that's going just to cost us money[…]the business would finish really quickly."* – **Ro1**

However, it was noted that if policy dictated that diesel was no longer allowed, it would be a level playing field for operators who would all have additional costs to pass on to the customer. Therefore they would not lose the competitive edge.

> *"If we can get a direction that we're going in, if it's hydrogen, and the cost of the trucks is 20 grand more, then over five years, it's going to feed into the cost, and the customers will have no option but to pay. It's not like [other local hauliers] will be competing to take our container truck to Aberdeen; we're talking something much more. This is a national strategy that we're talking on here, and this isn't competitive edge stuff."* – **Ro2**

When asked to rank decision criteria in their importance when procuring a low carbon freight vehicle, the group identified whole life cost as the most important consideration.

4.1.1.2 Range

The operators in this focus group had mainly long-haul operations which utilise vehicles continually. The vehicles have a high payload, which means that there is no suitable electric vehicle commercially available that could transport their loads. Even if a vehicle emerged with the payload capacity, the operators felt that the time required to recharge that vehicle would take too much time out of their operation to be suitable. In addition, it would need to recharge often, given the limited range such a truck would likely offer.

> *"[An electric truck] would never suit our operation. We double shift five days a week. So, when are we supposed to charge it?"* – **Ro4**
>
> *"It wouldn't be an option for me to run electric because the range on them is so poor, versus the payload."* – **Ro6**

Some operators have utilised LNG vehicles, which demonstrate a good technical solution in payload versus range and is a vehicle market that has seen a marked improvement in the past five years. However, infrastructure availability is a concern for those operating in remote locations.

"We look to double shift or triple shift vehicles, on average, around about 360 kilometres per trip. Coming back and looking at that, LNG would be the one we would go for. But with quite a lot of them, if you go for rigid vehicles, they're CNG, and we wouldn't get the range to get back to get refuelled and out." – ***Ro3***

When asked to rank decision criteria in their importance when procuring a low carbon freight vehicle, the group identified range as the second most important consideration.

4.1.1.3 Payload

For long-haul vehicles, operators can make a greater profit by delivering more goods in a single trip, so sacrificing payload for a heavier technology would cost money. In addition, batteries for electric vehicles are particularly heavy, making them unsuitable for these operators.

"When you're delivering in bulk, literally every little bit is additional payload. We've looked at [electric vehicles] to reduce carbon[…]but it's the weight of the batteries, and also the poor level of technology on it. The weight of the batteries makes a huge difference." – ***Ro6***

When asked to rank decision criteria in their importance when procuring a low carbon freight vehicle, the group identified payload as the third most important consideration.

4.1.1.4 Reliability and maintenance

Another consideration for operators is how reliable the vehicles are. It was considered that the reliability of gas vehicles has improved compared with five years ago, but this is still considered alongside the cost when making a purchasing decision; if a vehicle breaks down or is out of service, this will cost the company money.

"If it can't do the same as a diesel truck, then you're risking performance, you're risking what you're there to do in the first place." – ***Ro4***

"We have breakdowns, which mean that drivers are out of service overnight, and diesel is so flexible when it comes to things like that." – ***Ro4***

Low carbon vehicles cannot currently be serviced at most regular garages until widespread adoption, and garages have the capability and expertise to do so. This may impede the operation from sending a vehicle a long distance for maintenance, resulting in the vehicles being out of service for a longer period.

"If you've got to travel further to a specialist maintenance provider, that's going to add to your downtime." – ***Ro6***

"I'm not going to buy a truck if I've got to drive half a day to try and get it serviced." – ***Ro6***

Participants identified the vehicle's reliability as the fourth most important consideration when purchasing a low carbon freight vehicle.

4.1.1.5 Infrastructure

Whilst operators identified LNG vehicles as a suitable alternative for long-haul operations, many areas of the UK do not have the infrastructure in place to support refuelling. Some of the participating operators have an extensive network which includes rural Scotland. The operators felt they could not adopt new LNG vehicles until the infrastructure was in place. However, through conversations with infrastructure suppliers, they have found out that suppliers are unwilling to invest in installing infrastructure until there is a proven demand for it. This has led to a paradoxical situation between operators and suppliers.

> *"The infrastructure just is not there. It's chicken and egg[…]the areas we're going to with LNG. The facilities aren't there, so the vehicles that deliver the LNG have to be diesel because we can't use them anywhere else. So, the infrastructure would be the big driver."-**Ro1***
>
> *"So, if more and more people are buying it, and there's more and more provision of a refuelling station, it makes it a better decision. That's a bit the same as EV charging, isn't it? The more chargers there are, the more people buy the EVs, the better it gets." – **Ro6***

Rugby, England, was mentioned as an example of where LNG vehicle uptake has been successful. It is owed partly to its status as a logistics hub, meaning there is plenty of demand from many operators. Suppliers have built the infrastructure at DIRFT near Rugby. The popularity of LNG is growing, thus demonstrating an appetite amongst operators for adopting LNG vehicles where they can be confident they can be refuelled. When the DIRFT refuelling station was built in 2013, it could refuel 250 vehicles per day. An extension to the facility in 2020, driven by demand for more gas refuelling infrastructure, gives the station capacity for up to 700 trucks per day.

> *"Rugby is like the logistics capital of the UK, isn't it? And that place is getting busy, and people queue to fill up there now. So again, it's almost you've got to put it there before it generates the demand because you're not going to decide to buy the vehicle unless you can refuel it." -**Ro6***

There is a perception that more infrastructure is needed around the network for electric vehicles because of the limited range the vehicles can manage. Vehicles would be required to recharge in more places more often, but the infrastructure is not yet in place to support this.

Infrastructure was considered the fifth most important factor in the decision-making criteria for purchasing a low carbon freight vehicle. Infrastructure was ranked lower than whole life cost, range, payload and reliability/maintenance, which may initially seem surprising. However, the range, payload and reliability factors inform the operators whether the vehicle will be capable of moving goods for their operation. After this is considered are the operators then consider practical considerations like where the vehicle can be refuelled.

4.1.1.6 Incentives

It was reported in the focus group that operators need some incentive to decide to adopt low carbon vehicles if it is not to be moved forced by government policy. Whilst there are viable low carbon vehicle options suitable for some of the operators, the incentive to adopt these are lagging.

> *"You look at HVO* (Hydro-treated Vegetable Oil)*, you look at biodiesel, and there are huge greenhouse gas savings. But you as operators are not incentivised to do that in any way." –* ***Ro9***
>
> *"I think there could be some incentive with road fund licence, and certainly LEZ (Low Emission Zone) charges and some other bits and pieces that would encourage people down the road." –* ***Ro4***

A successful example of an incentive scheme is adopting LNG vehicles which has proven popular with many long-haul vehicle operators. The UK government's fuel duty freeze on natural gas means that operators are afforded a 50% tax saving on LNG compared with fuel duty on diesel until 2032, which could explain the uptake success compared with other low carbon fuels such as HVO.

> *"We're all in business to make money and deliver at the lowest cost. With regards to LNG, there's an incentive to use LNG as there's a fuel duty tax saving on LNG until 2032."-* ***Ro5***

The inclination for government to provide incentives was called into question by the participants; however, fuel duty from diesel is significant revenue for the government, and without the income from the sale of diesel, the government may have less money to invest in schemes to support infrastructure projects that would help progress the take-up of alternative fuelled vehicles.

> *"Who's going to fund infrastructure projects when diesel fuels and liquid fuels have stopped? They are a great money earner [for government]. Where's the government going to get that revenue to put in place the infrastructure[…]and to provide the fuelling facilities?" –* ***Ro1***

4.1.1.7 Government policy

It was evident in the focus group that the factor which would have the most significant impact on low carbon vehicle uptake is policy direction. Participants agreed that they are lacking direction from the government, and until the government's position is clear, they will be apprehensive about investing in certain low carbon technologies. It is imperative that policy is in place to inform operators about which technology they should be investing in and to offer some assurance that infrastructure will be put in place to support that.

> *"As an operator[…]we've been told that we're coming to the end of the fossil fuels[…]100% support that but really frustrated that we've not got a direction that we're going to go." –* ***Ro2***
>
> *"We need some sort of guidance policy and then work towards it. But I think if you just leave it to operators to make up their mind, it's going to take an awfully long time." –* ***Ro4***

Operators commented that there were many options available in terms of fuel types and vehicles. In order to make a decision, there is an onus on the operators to investigate the most suitable options, conduct price modelling and choose the most appropriate technology;

however that information is not readily available to them. A policy direction would be a big help in reducing the uncertainty in these decisions. It was also acknowledged that not all operators would be taking the time to consider the available options. Many will need the policy to act as the forcing hand to move away from diesel.

> *"The motivation for me to buy low carbon freight vehicles will come from the policy. We are not prepared, I have wasted lots of hours, and I do feel as though I've wasted time on this[…]I have no clue where I am going to take my business to achieve this low carbon fleet[…]I just don't know what route to go to get the best return for my business." –* ***Ro2***

Once there is a national strategy in terms of the future preferred fuel, operators will be more confident in their decision to invest in new technology. Suppliers will be comfortable supplying the infrastructure, which removes a barrier for operators.

> *"Once we know what way the market is going to take us, then the suppliers can put the infrastructure in, and we as operators can buy the trucks, the manufacturers can manufacture them, then we've got a route forward." –* ***Ro2***

4.1.1.8 Uncertainty

Operators expressed that they need certainty in their decision-making to make a purchase decision, not only in the costs associated with purchasing but in knowing that the infrastructure will be in place to support refuelling, that the supply chain is equipped to manage maintenance and certainty that future policy will support their operation.

The uncertainty associated with the residual value of new technologies makes them less attractive purchase options. Whilst operators acknowledged that the upfront cost of vehicles might increase if they are forced to move away from purchasing diesel vehicles, they noted that as long as this increase affects all operators equally as a result of a policy decision, then this poses less of a challenge, as the competitive edge of pricing for customers is not lost.

> *"I don't think anybody's guaranteeing batteries over five years[…]There's too much unknown, and nobody wants to take the risk."-* ***Ro4***
>
> *"One of the big challenges about low carbon is residual values….Nobody knows how much a five-year-old gas truck can be worth when there are one million kilometres on it. So[…]you end up paying over the odds." –* ***Ro4***

It was noted that currently, the government's objectives are not clear. Even before a policy is put in place, the operators said that it would be helpful to know the government's objectives to inform decision-making, for example, whether the focus will be on lowering greenhouse gas emissions or improving air quality at a local level.

> *"There's a confusion, are we going for low emission? Or are we going for low carbon? We're actually, I think, going for both, but they are two different things; we probably need two different supporting mechanisms." –* ***Ro9***

While the understanding of new technologies has improved compared with five years ago, thanks to early trials becoming available, the operators felt that there is still some uncertainty around how sustainable new vehicles will be in the long-term.

> *"You are risking it[…] what will be like four years down the line? And that is one of the factors. A lot of this is unknown."* – ***Ro4***

4.1.1.9 Geography

Network geography was identified as a limiting factor which affected several operators in the group. The participating operators all had large networks and felt that they could not deploy low carbon vehicles on remote routes because of a lack of infrastructure to support them. Diesel is reliable and in the occurrence of a breakdown, the operator can be confident that the vehicle will easily be rescued, even in remote locations. However, this assurance does not exist for alternative fuelled vehicles.

> *"I've got a very limited choice of where I can put these vehicles if I want to use the network, other than having to purchase my own kind of provision for being able to refuel[…]or even looking at backup booster packs, etc."* – ***Ro6***
>
> *"If you're doing it delivering to a geographically diverse customer base, you know that the infrastructure network is going to massively hamper where I can put these vehicles."*- ***Ro6***
>
> *"You could probably make an electric vehicle work in the middle of London if many of your customers were in one small location. But again, it depends on the geography, your customer base and where you're going to put the equipment."* – ***Ro6***

However, other freight operation models may be better suited to low carbon vehicles, such as a hub and spoke delivery where routes are pre-determined and regular.

> *"If you're doing kind of a hub and spoke delivery, so if your supermarket that's supplying your DCs, you know how far you're going, you know where you're going to fill up."* – ***Ro6***

4.1.1.10 Driver comfort

Operators need to consider how to make their company attractive to drivers, particularly concerning the current driver shortage in the UK, which is expected to worsen following Brexit. The UK currently relies on a lot of European nationals as long-haul drivers. It was not determined whether there would be any sacrifice to driver comfort in adopting low carbon vehicles. However, the vehicles would need to be capable of housing amenities for drivers, such as in-cab lights and refrigerators for personal use, without having a significant impact on fuel consumption.

> *"The driver comfort things […]some of these can make or break whether somebody wants to work for you or not."* – ***Ro6***

4.1.1.11 Specialist kit and training

A vehicle's compatibility with the kit is a key consideration depending on the type of operation. For example, some vehicles require refrigeration units for transporting temperature-sensitive goods or ancillary equipment to support a vehicle's specialist use. A low carbon vehicle would need to have the capacity to meet these needs for the operator to consider the purchase.

> *"99% of my fleet[…]are all refrigerated. And at this moment in time, they're all diesel driven. So I've got to take into consideration when I'm sourcing a vehicle, it's not only what type of fuel the vehicle's going to need to power, it's what other ancillary equipment I have on there, which then greatly influences the cost of the vehicle." –* ***Ro3***

Operators also noted that a low carbon vehicle would be more attractive if specialist driver knowledge were not required, as additional driver training has a cost implication.

> *"That was one of the attractive things when we looked at LNG is that – take it to the fuel station, and they will fill it up for you. So, we didn't have to bother with driver training." –* ***Ro4***

4.1.1.12 Safety

Whereas five years ago, safety features were purchased as ancillary to the vehicle itself, nowadays, it is more commonplace for vehicles to come with safety features built-in. This is a more attractive package to the operator and simplifies the cost calculation when purchasing a vehicle.

> *"I think the one thing that's changed is safety. So if you go back to 2014-15, you had the option to add in autonomous emergency braking and other bits and pieces that you could add to the spec that would add cost then, but now that all come as standard. So, in terms of safety, you need to have less input because it's already taken care of." –* ***Ro4***

4.1.1.13 Varying operator requirements

A key point emerging from the discussion was no 'one size fits all' solution. The long-haul operators acknowledged that they have specific requirements such as very high mileages and double or triple shifting a vehicle. These challenges would not necessarily be shared by van fleet operators or heavy goods operators with a different logistics operation such as a hub and spoke delivery model.

> *"The key element from this discussion is [that] not one size will fit all. It depends on the application, and a truck has very varied applications, as we're all already discovering."-* ***Ro5***
>
> *"See, when you're talking about a van fleet, you're not talking about double shifting and heavy road freight." –* ***Ro6***

There is a frustration that sweeping legislation will not consider individual business needs, or even the varying needs of a mixed fleet.

> *"The frustration is on that side of things, trying to get people to actually come in and take into consideration what your business requirements are." –* ***Ro2***
>
> *"There are different requirements from different applications, even within fleets, there are different requirements." –* ***Ro2***

4.1.1.14 The environment

Whilst operators would like to reduce GHG emissions, this is not a current priority. Although the desire to reduce GHG emissions is apparent, and operators understand the benefits to the environment, the incentive in terms of benefit to their business did not exist.

> *"Not one operator has said one of their considerations is what the greenhouse gas savings are? And that is completely understandable because they've got to run a business. And frankly, what's the point of worrying about GHG emissions?"* – ***Ro9***
>
> *"I don't think that there's a company on the call who wouldn't go green if they didn't have the opportunity, who wouldn't do the right thing."-* ***Ro4***

Customers tend to look favourably on operators who offer a lower carbon solution, as it feeds into their corporate responsibility. However, this is not enough benefit for customers to agree to pay more, so lower costs are still a priority in terms of customer demand.

> *"The majority of people are going to be looking at price margin rather than anything to do with what we do on carbon."-* ***Ro6***

4.1.1.15 The role of OEMs (Original Equipment Manufacturers)

It was generally agreed that the manufacturers and OEMs should take a leading role in driving development and shaping future technology because they are well placed to design a solution that meets operators' needs. However, it was noted that the manufacturers would need to be guided by legislation first.

> *"I think the catalyst to change will be with the manufacturer. They have the most knowledge[…] to develop the best solution – reliability, cost, emissions. And I think it's going to be driven by the manufacturers, and I think we should listen to the manufacturers."* – ***Ro2***
>
> *"The other thing, about the OEMs, and the vehicle manufacturers taking the lead is[…]you are reacting to the government legislation."-* ***Ro9***

4.1.1.16 The role of LNG suppliers

Operators discussed installing their own LNG supply to overcome the infrastructure barrier. However, suppliers of LNG will not provide infrastructure unless there is enough demand. There is currently not enough demand for suppliers to supply LNG in the areas they were operating in, such as rural Scotland. Before the infrastructure is in place, the operators stated that they would not purchase LNG vehicles.

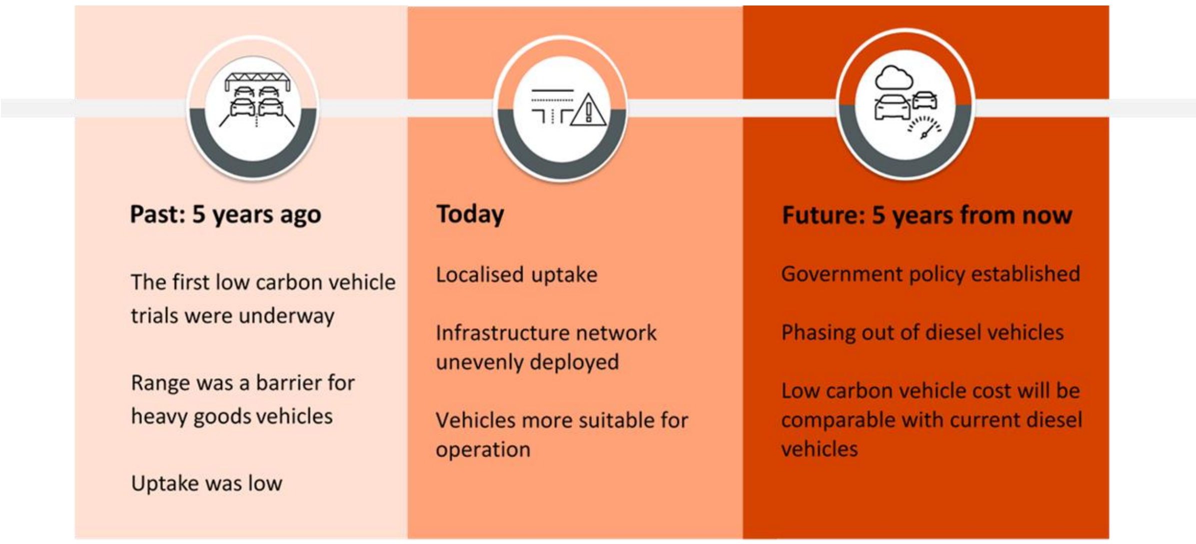
> *"At the start, most suppliers of gas are looking at a minimum of 5 to 10 vehicles before they'll even look at supplying."* – ***Ro3***
>
> *"I know of four or five operators around the area who are quite keen to do a gas conversion. However, when you're talking to the suppliers, we don't seem to get anywhere. One of the operators has put in a concrete plinth to take in a gas station. But because they can't secure the number of vehicles that are required, they can't get a commitment from a supplier."* – ***Ro3***

With electricity supply, there is a concern that there is not enough electricity in the grid to support the fleet.

Table 4.1 Summary of the enablers and barriers of purchasing low carbon road freight

Barriers	Enablers
• **The infrastructure is not in place to support gas refuelling, and the fuel suppliers are reluctant to install infrastructure where demand is low.** • **There is no clear policy direction from government.** • **There is a lack of knowledge about the available vehicle technologies and what is suitable for each operation** • **Operators need an incentive to move away from diesel, whether from cost savings or government policy.**	• A suitable technology is available. **LNG vehicles** offer a **good technical solution** to meet the operational needs of long-haul operators in terms of the **size**, **payload,** and **range** of the vehicles. • Although there is a higher upfront cost of low carbon vehicles, this is absorbed into the **WLC,** and **cheaper fuel** and improvements to **fuel efficiency** would allow payback over the purchase period.

Table 4.2 Changes over time in the long-haul road freight industry



4.1.2 Public Sector

4.1.2.1 Infrastructure

The public sector is eager to supply infrastructure to support the uptake of low carbon vehicles. It is critical that infrastructure is in place before people will choose to move away from diesel-fuelled vehicles. Participants mentioned that they were considering the charging hub model where EV charging infrastructure is supplied in a forecourt setting for public use. However, it is noted that this approach would support the use of electric vehicles as personal cars rather than for the movement of freight. The importance of a green energy supply was noted, with the infrastructure's requirement to be in place before uptake can become widespread. Participants reported that the public sector supports hydrogen uptake within their own fleets and installs their own infrastructure as part of the process.

> *"The issue we've had is that people are interested in zero-emission vehicles, but their first question is, where is the infrastructure to refuel them. But then when you talk to the infrastructure providers, they say, where's the demand for the vehicles, so you have to align those two at the same time to get both to go ahead." –* ***PS3***
>
> *"At this moment in time, when introducing hydrogen vehicles for a trial project, the refuelling infrastructure will be provided as part of the trial if it's not there already "-* ***PS2***
>
> *"There's quite a lot to think about around infrastructure; especially if you're a reasonable sized logistics supplier with a considerable number of vehicles, then infrastructure is going to be fundamental to whether you can shift to a low carbon vehicle or not." –* ***PS6***
>
> *"I guess as range increases, the pressure on infrastructure drops a little bit equally, the number of vehicles we're running increases, so there's more infrastructure required."-* ***PS4***

When ranking the decision-making criteria for the procurement of low carbon vehicles in the focus group, the public sector ranked infrastructure as the most important factor.

4.1.2.2 Whole Life Costs

The participants calculate whole life costs (WLC) when making purchasing decisions. There was agreement that electric vehicles are an investment which is cost-effective in terms of WLC due to the inexpensiveness of electricity compared with diesel. The participating operators have been able to justify the acquisition of new electric vehicles without sourcing additional funding because the WLC business case demonstrates that they are a cost-efficient purchase over the vehicle lifespan.

> *"We've not accessed any external funding for our electric vehicle fleet. We've purchased each vehicle based on the business case that, if you're doing around 8000 miles a year in an electric fleet vehicle, then electric vehicles will pay back over the whole life cost."-* ***PS4***

Whole life cost was identified as the public sector group's second most important decision criteria.

4.1.2.3 Funding

Some funding is available from the government to support operators with the upfront cost of low carbon vehicles. However, it was felt that more is needed to support the rollout of infrastructure and to cover any additional costs associated with training the supply chain in how to operate and maintain new technology. Funding schemes so far have tended to focus on lowering tailpipe emissions to help vehicles become compliant with Low Emission Zone rules. However, the low carbon agenda is relatively new. More government funding to support the decarbonisation goals would be welcomed. Participants felt that it is the responsibility of regional authorities to lobby the government for such funding.

> *“There are grants available for buses, but also HGVs, for retrofit solutions, which tend to be aimed at Euro 5 vehicles, but this is more aimed around air quality, the NOx emissions.” – **PS1***
>
> *“For city-scale infrastructure, that's where the finance is required.” – **PS4***
>
> *“If the future is hydrogen, or if the future is electric, we need to have those programmes and funding in place that supports the development of those supply chains, and the training programmes and the apprenticeship programmes.” – **PS1***

The availability of funding was identified as the third most important criterion in the decision to procure a low carbon vehicle.

4.1.2.4 Suitability to task

Different local authorities have their unique issues, so there is no ‘one size fits all’ solution. For example, some local authorities will be able to operate an electric refuse collection vehicle, whereas others will need a much larger refuse collection vehicle which requires a much higher payload to be suitable for the electric options that are currently on the market. There is a need for a mixed approach - the public sector is focused on hydrogen and electric for their vehicle fleets. However, participants discussed the need to consider taking freight out of motorised road vehicles altogether and adopting micro-mobility or rail where appropriate.

> *“It's not all about hydrogen, it’s about a mixed economy, between hydrogen and electric[…]and whether that necessitates regional infrastructure, as opposed to local city infrastructure, because heavier vehicles are on the motorways more, and coming into cities along key routes, whereas your EV infrastructure, potentially is more specific to fleets, whether that's a depot or home-based, or at critical points like a community hub [where EV recharging facilities are provided in a forecourt setting similar to a petrol station which is open for the public and private operators to use].” – **PS1***

The suitability to the task was the fourth most important factor in the decision-making criteria.

4.1.2.5 Upfront costs

Participants expressed a concern that the upfront costs of investing in low carbon vehicles (and associated infrastructure) would be prohibitive to private sector operators. To overcome this, some participants in the group are purchasing low carbon buses to lease out to bus companies to support the adoption of low carbon vehicles in their local authorities. However, it was noted that over time, the premium cost of low carbon technology is likely to decrease in line with diesel vehicles due to economies of scale when the production of low carbon vehicles increases.

There is an expectation that private sector operators will wait until the technology is older and therefore less expensive before purchasing a low-carbon vehicle.

> *"There's a premium for alternative fuel vehicles and electric cars[…]in terms of the upfront cost of the vehicle. Of course, there are grants available and stuff like that, but actually, for an operator to make that change to that new technology is quite a leap of faith."-* ***PS6***
>
> *"On our bus fleet, we're having to buy the buses and own them because the operators are concerned, obviously, with Covid, their revenues aren't as high as they usually are. And the viability for an operator to do these new technologies isn't as good as it used to be." –* ***PS3***
>
> *"The cost of retrofitting a Euro six to become electric is just not possible because it's just cost-prohibitive." –* ***PS1***

4.1.2.6 Scrappage

To encourage private-sector operators to adopt new low carbon vehicles, a scrappage scheme should be put in place to incentivise the disposal of old diesel vehicles. Without this incentive, operators are likely to utilise old vehicles for as long as possible. They may look to retrofit older models instead of investing in a new, low carbon fleet.

> *"There's also the need for a scrappage scheme because this target by 2030, or 2035, to stop the sale of existing petrol and diesel vehicles. And I don't think it necessarily covers HGVs yet; they still think about what to do on those. But if they're trying to incentivise that, what do they do with the current vehicles, whereby the vehicles may be perfectly fine, it's just a fuel that's the problem or the propulsion technology." –* ***PS3***

4.1.2.7 Ownership model

There may be a change in the ownership model of fleets to promote uptake of low carbon vehicles, with the public sector owning and leasing low carbon vehicles to operators. This is already done to support the uptake of electric taxi and private hire vehicles in Liverpool.

> *"There may be more need for the public sector to step in and help transition to these newer vehicles by directly having to own them for a period and just a leasing mechanism. Because currently, bus operators and freight operators tend just to procure vehicles directly themselves. Whether that model is going to continue, we're not sure." –* ***PS3***

4.1.2.8 Procurement

The public sector will use GHG emissions as a decision criterion in tenders to help support the decarbonisation of the supply chain, favouring companies who can demonstrate low carbon credentials. In this way, the public sector influences purchase decisions.

> *"If I can speak for [my local authority]. We're doing [GHG as decision criteria in tenders]. And also, for things like HS2 contracts, there's a requirement. So we are*

> *passing it down the supply chains where, as a local authority, we have more influence.” –* ***PS1***

4.1.2.9 Payload

Payload and the weight of batteries were not a big concern for the public sector operators as they tend to operate smaller vehicles which are appropriate for electric powertrains.

> *“Fundamentally, I don't think it is that big a shift to electric vehicles […] for the smaller end of the market at the moment.” –* ***PS4***

4.1.2.10 Immature technology

Participants felt that a suitable low carbon technology is not yet available for the larger vehicles in the fleet, such as the heavy-duty refuse collection vehicles. The largest vehicles in the public sector fleets have a lifespan of around ten years, so for many of the participants, suitable low carbon vehicles did not exist at the most recent opportunity for procurement, meaning that even where suitable vehicles have recently emerged, uptake is not yet widespread.

Perceptions of low carbon vehicles have improved with advancements in vehicle range, so EVs are now a more viable option for many fleets.

> *“It is challenging because, during the last round of procurement for these vehicles, the equivalent electric or zero-emission bin wagons that we would require were not available.” –* ***PS1***
>
> *“We're involved in the rollout of EV infrastructure in [this city] and planning to meet the net-zero requirements by 2030. But from our modelling, by 2030, we could only ever achieve 51% towards that net-zero. And that's because vehicles just simply are not on the market… the life cycle of all of these vehicles tends to be 10 to 15 years,” –* ***PS1***

4.1.2.11 Air quality legislation

Purchasing decisions in the past have been based on the government's air quality agenda. However, now the agenda is moving towards decarbonisation.

> *“Because the experience that we've had particularly in the procurement of bin wagons, bearing in mind that the life of these large vehicles tends to be towards 10 to 15 years, it’s alignment with the local government and national government policy regarding air quality.” –* ***PS1***

4.1.2.12 Local government policy

Much of the uptake of low carbon vehicles within the public sector has been driven by the local authority's targets. Many local authorities have declared a climate emergency and have targets to reduce carbon, which they are already progressing towards. These targets will set them ahead of the central government's targets to be net-zero by 2050. The local authorities have also undertaken measures to decarbonise their supply chains, which they believe has had a bigger influence over low carbon vehicle take-up than the central government's plans which are not clear yet in terms of how to decarbonise. The public sector would like the central government to take a bigger role and expect this to happen over the next five years.

> *“I think it's fair to say that local authority policies determining decarbonisation are probably ahead of government requirements.” – **PS6***
>
> *“The authority to go and be able to procure is based on the fact that there is legal approvement to be able to do this, the reason why you have to do it is that there's a regulatory requirement, government policy, or it's a cabinet commitment.” – **PS1***
>
> *“It's for the public sector, through their procurement frameworks, actually starting to specify the need for zero-emission for those commercial vehicles that are part of the supply chain delivery for construction, or whatever, within the city.” – **PS1***

4.1.2.13 Policy

The public sector participants noted that it should not be local authorities that lead progress on the decarbonisation agenda because success is reliant on a joined-up approach. Otherwise, networks of infrastructure would be fragmented depending on the priorities of each local authority, for example, if one area invests in electric charging infrastructure and another in hydrogen refuelling. Therefore, a national strategy from the central government is required to enable the standardisation of infrastructure across the UK. The group expected that the climate change agenda will drive decisions made by central government.

> *“The government net-zero targets for 2040. But many city regions are having a serious difficulty in working out how you get there.” – **PS3***
>
> *“There's going to be a need for government decisions to standardise sockets and payment platforms so that people can focus on the important bit, which is clean vehicles and the refuelling infrastructure.” – **PS3***
>
> *“I think it's a real cop-out when people talk about what the local authorities are doing. Because this is a bigger issue, this is a transport strategy. That's a national question. If we're going to have a national scale switch to hydrogen, and EV, then there needs to be national-scale infrastructure put behind that. And really, that's kind of beyond local authorities.” – **PS4***

4.1.2.14 Gas vehicles

A barrier identified by one public sector operator was that they could not get the refuelling infrastructure in place to support a new natural gas vehicle because there was not enough demand for the fuel supplier to commit.

> *“A few years ago, we were looking at CNG as a solution for heavier vehicles. So we worked with the northern gas networks to look at development, and we got some funding to scope out a city-scale CNG station. But unfortunately[…]there is no vehicle because there's no infrastructure, the vehicles aren't there, and so on. It didn't get off the ground.” – **PS4***

4.1.2.15 Uncertainty around costs

Some of the costs associated with low carbon vehicles are unknown, particularly the cost of retraining and adapting the supply chain and maintenance workers and the depreciation of the vehicles' value. Also, there is a question about the loss of government revenue through fuel duty, whether this will be replaced with another tax and any impact on the cost of adopting low carbon vehicles.

> *"Whole life costs are key when you're comparing old technologies with new technologies, and technologies that people trusted for a long time, alongside new technologies that probably have been tested for their functionality but don't operate in the real world. It's trusting the figures the manufacturers have given you." – **PS6***
>
> *"Do you need funding to upskill your workforce to handle electric vehicles or hydrogen?" – **PS3***

4.1.2.16 Uncertainty around actions

It is unclear what actions the public sector needs to take to meet decarbonisation targets. There are alternative ways to move goods that may become more mainstream, such as micro-mobility options. The market for hydrogen production is still very small in the UK, and it is not known how quickly it will grow. At the moment, there is a lot of reliance on Europe for the supply of energy, but the implications of Brexit add a layer of uncertainty.

> *"It's proven quite a challenge to work out what needs to be done, and whether it's practically possible and financially possible to deliver to meet that fixed timescale and target." – **PS3***
>
> *"I know from the hydrogen deployment that we're doing that some parts of the electrolyzing process come from Europe. So nobody can travel at the moment. And obviously with Brexit as well puts the degree of uncertainty in that."- **PS3***

4.1.2.17 Technology

Currently, the public sector feels that it is unclear which technologies exist, most applicable to different tasks, and whether (and when) new technologies might emerge. They expect that in five years, the picture will become more apparent.

> *"We can have a really good conversation with somebody with expertise, saying hydrogen is the answer for everything else. And then the next day, we get responses from people who are also experts in the field saying it's a red herring, don't touch it with a barge pole[…]I think that's partly part of the challenge, which technology is going to win out?" – **PS6***
>
> *"If you're not aware of what a low carbon vehicle option is for you, and what it can do for you and where to get it, you won't even consider it." – **PS3***

4.1.2.18 Decarbonisation

Compared with five years ago, the public sector has noticed a shift toward the decarbonisation agenda, where the focus was on air quality and emissions earlier. Hydrogen is one possible solution to decarbonise, but participants commented that the credentials of hydrogen (wheel-to-wheel rather than tank-to-wheel) are unclear. There is uncertainty around which fuel will offer the best solution.

> *"[There are] possibly dubious green credentials of hydrogen, depending on how it is generated." – **PS4***
>
> *"I think decarbonisation and climate emergency type issues weren't such a high profile about five years ago; it's only in the last two or three years they've become an urgent, important thing." – **PS3***
>
> *"I think it was air quality five years ago; it'll be carbon now. And I think the challenge is not to forget air quality, whilst we focus on carbon."- **PS4***

4.1.2.19 Mobility hubs

Participants reported that a major topic under consideration by public sector organisations is how to reshape the freight model in cities. Part of this might involve restructuring movements through mobility hubs to manage freight flow in response to the effects of rapid urbanisation and e-commerce. This approach focuses on vehicle movements rather than the vehicles themselves but could benefit the decarbonisation agenda because it would ease congestion in cities and reduce vehicle miles.

> *"With the rise of online shopping, do we need a network of parcel lockers or links with post offices to enable all the urban logistics?" – **PS3***
>
> *"We've got future transport zone funding to look at setting up mobility hubs and smaller-scale versions, mobility points; it's going to be about local pickup, reducing the amount you have to travel, potentially combining charging points with those mobility hubs." – **PS5***

4.1.2.20 Behaviour change

Behaviour change is a new conversation in the public sector and is still in the early stages. The need for additional land for mobility hubs is a barrier. The public sector needs to encourage private sector organisations to engage with the process.

> *"There is an issue, that with the explosion of online deliveries, and where retail is going more online, it will ultimately impact our roads decarbonisation and the impact on climate change[…]. As a nation, it is actually about behaviour change." – **PS1***

Table 4.3 Summary of the enablers and barriers for public sector freight

Barriers	Enablers
• **Public sector operators have a mixed fleet and require different vehicle technology solutions for different tasks** • **Suitable vehicles have not been developed for the heavier vehicles in the fleet, such as refuse collection vehicles** • **The public sector is unsure which infrastructure to invest in**	• Clear **guidance from central government** would allow a **unified approach** • The public sector is making progress in decarbonising their **supply chains**

Table 4.4 Changes over time in the public sector

Past: 5 years ago	Today	Future: 5 years from now
The focus was on air quality rather than decarbonisation Some trials of electric vehicles for refuse collection	Uncertainty around the vehicle options available and which are most suitable Infrastructure network is not wide-reaching enough Electric vehicles are relatively widespread	Government will define their route map to decarbonization A clearer picture of the technologies available and the government's preferred approach

4.1.3 Rail Freight

4.1.3.1 Whole life cost

Due to the market's immaturity, the upfront cost of purchasing low carbon rail assets is not yet known. However, it was noted that any modifications to reduce carbon output would have a significant cost implication.

> *"There's not a ready answer to whether there's a big upfront cost difference between low carbon and diesel rail."- **Ra2***

> *"For the other technology offerings in a zero-carbon direction, there's not a locomotive design yet, or a price list from which we evaluate. So, it's a big unknown, the capital costs of the units because they don't exist yet." – **Ra2***
>
> *"There's also an element of economies of scale in terms of a modification to a loco; you can't generally do one or two; you would need to make it more cost-effective, and look at a much larger number." – **Ra6***

By ranking the operators' decision-making criteria, the asset's cost was identified as the most important factor for consideration of procuring a new low carbon rail asset.

4.1.3.2 Government commitment to rail freight

The operators noted that the rail freight sector is waiting for direction to understand the government's ambitions regarding the future of rail freight and its status compared with other freight modes. If the government supports the industry, this should be reflected in revenue support and set in stone through clear policy.

> *"It's understanding what future government policy is and that's like multi-faceted[…] whether the government are supporting rail freight through mode shift revenue support grants, through how they might have a choice, freight or passenger service going forward." – **Ra1***
>
> *"Whereas in the future, it would be government's commitment and policy to delivering electrification." – **Ra3***

The government has not made a clear position on rail freight and participants felt that the government's freight strategy had overlooked the rail sector. If the government commits to supporting the growth of rail freight, then organisations can make investment decisions.

> *"The government's ten-point plan to recovery, I think rail freight was missed off somewhat." – **Ra6***
>
> *"Commitment to freight policy by the government is probably the best proxy we have in terms of assessing the growth potential going forward." – **Ra5***
>
> *"Rail freight needs to feature prominently in government thinking and policy." – **Ra6***
>
> *"I think the next few years will be setting up the future, in terms of the electrification appetite by government." – **Ra1***

4.1.3.3 Policy

To make purchase decisions, specific policy plans for rail freight are essential. The current lack of policy direction is the most significant barrier for decision-makers.

> *"One of the biggest factors of all is what the government policy on electrification is going to be, which we don't yet know." – **Ra1***
>
> *"It very difficult to start choosing to invest in them now for private sector investors, particularly against the policy uncertainty that's been described." – **Ra2***

> *"The present uncertainty in the markets about what, where precisely the destination of decarbonisation might be, it's very difficult for the moment to justify finding new traction." –* ***Ra2***

The participants ranked government commitment and policy direction as the second most important criteria in the decision-making process for procuring low carbon rail.

4.1.3.4 Infrastructure

Operators in the group stated that purchase decisions could not be made until there is certainty over what infrastructure will be in place and whether it will stay in place for the duration of the asset's use. Infrastructure to support low carbon rail is limited at the moment.

> *"If someone does invest in a fleet of electric locos, or whatever, or any research, are we guaranteed that the infrastructure will be there to allow us to make the most of these investments over the next 30 or 40 years?" –* ***Ra4***
>
> *"At what point are we confident that the infrastructure will be in place, whether it's battery power, electric or hydrogen in the future? How confident can we be if we make that investment now that it will be there in the future for us to use as well?" –* ***Ra4***
>
> *"At the moment, there is no easy choice until we know what electrification is going to take place." –* ***Ra1***

Infrastructure ranked as the third most important criterion in the decision to procure low carbon rail assets.

4.1.3.5 Capital risk

Investment of capital in new technology is risky due to the long lifespan of rail assets and the uncertainty around new technologies which could emerge and take over due to the rate of new developments. This is a barrier to making purchase decisions and accessing finance to buy new rail assets.

> *"We couldn't buy a locomotive for the next 40-year future with any certainty, and on that basis, financing it would be difficult."-* ***Ra2***
>
> *"The cost of buying an imperfect technology at this stage, and going for something that's, by mode, probably a bit heavier, and the risk of more mature technologies emerging five to ten years, which are more advanced in decarbonisation etc." –* ***Ra5***

4.1.3.6 Funding

With the current uncertainty around the future of rail, private investors are reluctant to pay to support any trials and infrastructure that would help initiate the transition to low carbon rail freight. Therefore, the industry relies on the government to supply funding to accelerate low carbon rail uptake.

*"Specifically, on the cost of infrastructure, there comes the point that the government, I think has to grit its teeth and if they want this to happen is going to have to fund some electrification." – **Ra2***

4.1.3.7 State of the market

To make purchase decisions in low carbon rail stock, investors need some certainty that the rail freight market is growing. Certainty could be provided by government policy supporting rail freight, but the government position is unknown.

*"From a rolling stock leasing perspective, obviously funding, either procurement of new or investing in existing, we want to know that the market is vibrant and growing." – **Ra6***

*"Certainly, key for us investing in assets is a long-term future for those assets. So, the market growth and strength of that is quite key." – **Ra6***

*"One quick comment on market growth. In my mind, this is probably the most critical[…] government policy underpins a lot of that." – **Ra6***

4.1.3.8 Longevity of asset

Rail assets have a long lifespan and are typically utilised for 35 years. Therefore, investors need certainty that the technology and the infrastructure will last that long. However, with new technology, this has not been demonstrated, so purchasing new technology is risky. Whilst the participants acknowledge the government has been clear in its aim to phase out diesel, the industry has not been given a clear indication of what type of low carbon technology to invest in now.

*"What is a constant question for anyone investing in the fleet is how much life expectancy we'll get out of the investment" – **Ra4***

*"The asset life of locomotives is typically 35 years. We're now at a point where there isn't really a choice to buy a diesel-only locomotive, our choices have to be low carbon." – **Ra1***

4.1.3.9 Technological readiness

Whilst overhead electrification offers a solution to decarbonise rail freight assets, the network of overhead electrification is not wide enough for the freight operators to utilise at this point. Although some alternatives are being developed and suitable for passenger rail, they cannot offer the range and weight requirements demanded by rail freight. The industry knows it needs to move away from diesel, but there are concerns that the perfect solution will not be found. There is an expectation that solutions will be developed over the next few years; now, the industry is focused on decarbonisation.

*"Diesel has the mark of death over their heads. And there's not yet a viable alternative." – **Ra2***

*"I think the next few years will be setting up the future, in terms of the development of technologies that could be used alongside electrification." – **Ra1***

> *"The alternatives are not yet available[…]there isn't yet any technology, apart from electrification and diesel, that is proved to be powerful enough to haul freight trains."- **Ra1***

Participants felt that hydrogen is not a viable technology to deploy currently.

> *"At the moment, there's nowhere demonstratively that you can deploy hydrogen in rail freight." – **Ra2***

4.1.3.10 Range and payload

Participants reported that diesel meets all the speed, capacity, and fuel efficiency requirements. Some infrastructure has been updated for electric rail, including the installation of overhead electrification. However, to further proceed with batteries or fuel cells, the track infrastructure will need to support the payload (heavy axle loads). There is concern that new technologies will take up so much weight in onboard equipment and fuel storage for batteries or fuel cells that the payload of goods would be reduced. This would have a cost implication for operators whose profit would be reduced if weight limits reduce the number of goods they can move.

> *"There's not a fully developed technology, which can package enough power and range into a thing the size of a locomotive, actually to do the job." – **Ra2***

4.1.3.11 Test trials

Participants reported that some low carbon test trials had been carried out. However, the operators in this group had been unsuccessful in their applications to participate. There is a feeling that more trials (and more funding from the government for trials) are needed, and this would help inform future purchase decisions.

> *"There's been one or two quite small-scale trials of some technologies. They've been proven very difficult to get off the ground thus far." – **Ra2***
>
> *"There is some funding available in competitions[…], but it's quite difficult to win those competitions." – **Ra1***

4.1.3.12 Suitability to task

Currently, electric rail is the only low carbon asset demonstrated as a viable solution for rail freight, though there are still limitations. There is an expectation that investment in battery technology will lead to improvements over the next few years. However, an added obstacle is that specific routes must be electrified before electric rail can be deployed, so the operators are limited in their application.

> *"The conversation we will continue to have over[…]five years is going back towards greater electrification because it is the only technology which demonstratively can handle the demands of heavy freight." – **Ra2***
>
> *"Today's movements will be very much dictated around gauge and route availability from a weight perspective." – **Ra3***

> *"In the future[…]movements would be very much more focused around the availability of electrification." – **Ra3***

4.1.3.13 Speed of progress

Progress for installing infrastructure to enable electrification is slow, but some work has been done to electrify the routes. Until the further infrastructure is installed, there is a reluctance to invest in new rail stock. The slow progress in electrifying the routes means that the transition to low carbon rail is taking longer than was anticipated.

> *"Is the infrastructure going to be there in the future to allow us to invest in that?" – **Ra4***
>
> *"Rail tends to be a bit more of a slower process. I mean, there's much more to consider perhaps." – **Ra6***
>
> *"The railway putting infrastructure in place is relatively slow. At what point will alternative methods of power overtake that?" – **Ra4***

4.1.3.14 Timescales for purchasing new technology

Operators are uncertain of what rail assets to invest in and when. There is apprehension about making the decision too soon as a more suitable technology may emerge in a few years, which is a decision made more difficult given the long lifespan of rail assets. The alternative technologies are too immature to make an investment decision that operators are confident will be the right one in the long term.

> *"Ultimately, we need to replace them, but at what point do we replace them?" – **Ra4***
>
> *"At the moment, there is no easy choice until we know if and when other technologies develop enough to have a more suitable locomotive." – **Ra1***
>
> *"It would be good to see some sort of modelling[…]at what point will future technologies overtake the speed of infrastructure being put in in the railway?" – **Ra2***

4.1.3.15 Decarbonisation agenda

The participants noted that decarbonisation of the rail industry is a relatively new topic of discussion which has emerged within the past five years. It is expected that this topic will gain more precedence, with more ambitious goals expected to be implemented.

> *"[Since five years ago] in terms of the societal change, there's certainly a lot more focus in general on decarbonisation, and green transportation." – **Ra6***
>
> *"Speaking to end users, I think their knowledge and awareness of decarbonisation has grown[…] five years ago it might not have been as hot a topic as it is now." – **Ra6***
>
> *"Five years ago, it's probably just a diesel locomotive because there weren't as clear government policies on carbon and the need to move away from diesel."- **Ra1***

4.1.3.16 Carbon cost

Rail is already a relatively low carbon means of transport compared with other freight modes. The potential further savings are minimal percentage-wise compared to the whole transport sector and suggested this might be why much of the focus has been on decarbonising road freight, where there is potential for more significant improvement.

> *"We should remind everyone, [rail is] very low carbon compared to the other, the main competition, which is the road."* – ***Ra2***
>
> *"Rail freight produces so little carbon, the numbers [when looking at lower carbon options] don't look very compelling."* – ***Ra2***

Table 4.5 Summary of the enablers and barriers for rail freight

Barriers	Enablers
• **Suitable low carbon rail assets have not been developed apart from overhead electrification** • **Electrification of the infrastructure is not yet widespread enough** • **The long lifespan of rail assets means that certainty of the future of rail is needed before a purchase decision can be made**	• Along with overhead electrification, **electric** rail seems like a suitable alternative, and developments in **battery technology** are underway to support this • More widespread **overhead electrification infrastructure** would support decarbonisation • A clear **policy direction** from the government on the future of rail freight would help investment decisions

Table 4.6 Changes over time in the rail freight industry

Past: 5 years ago	Today	Future: 5 years from now
Decarbonisation was not a discussion in the rail freight industry	Uncertainty around the future direction of rail freight	New solutions being developed
The appetite for rail freight seemed to be declining	Some discussions around decarbonisation	More ambitious goals for decarbonisation
	Localised deployment of electric rail	Infrastructure more widely installed

4.1.4 Maritime Freight

4.1.4.1 Upfront costs and benchmarking

The participants noted that the cost of operating ships is considerable, with typical fuel costs of around £10000 per day. Purchase decisions are informed by benchmarking costs against a model ship to enable an in-depth analysis of all energy-saving measures that will affect the cost. This benchmarking exercise is carried out for every chartered ship across all maritime operations.

> *"I have to keep the operating cost of the vessel far below the operating cost of a benchmark[…this…]requires an in-depth analysis of every piece of equipment on board to make a cost-benefit analysis. That means investment versus maintenance costs."* – ***M1***
>
> *"If you have a ship with a certain efficiency and you want to improve the efficiency by retrofitting; you have to calculate the benchmarking that your ship will receive afterwards and the payback period."* – ***M1***

Low carbon ships are not currently available to buy commercially because the technology is not fully developed. Even if the development of low carbon vessels accelerates, the cost of alternative fuels would be a big deterrent: ammonia engines currently cost around twice as much as the combustion engine for diesel or low-sulphur fuel oil used. There would be additional costs associated with adapting the vessel. Participants stated that ammonia is likely to be the most popular option for low carbon vessels given its suitability in trials. However, the installation cost and the fuel cost are high.

> *"The new technologies for the new ammonia energy will cost maybe 50% more than the standard combustion engines. If you go to fuel cells, the price is even multiplied by two or three times." –* ***M1***
>
> *"If the cost of low carbon fuels is five times what it is now; if they want a lot greener transportation, they've got to be prepared to pay for it." –* ***M2***
>
> *"Once you are left with these really expensive fuels, you'll be incentivised to do everything to make your ship super-efficient because you will want to use the least amount of the costly fuel" -* ***M1***

4.1.4.2 Incentives

Currently, fuel costs are relatively low compared to alternatives, so operators are not incentivised to adopt an alternatively fuelled ship. To justify a purchase decision for a low carbon ship, the operators would need some incentivisation on the price or for the price of the current fuel to increase. The cost of new technologies will be very high, and no operator would be willing to adopt them early without incentive. This feeds into the benchmarking process, where operators have to benchmark the cost of a new purchase against a model ship.

> *"We need to discuss the incentives[…] for a ship owner to proceed and invest the money to build the ship on zero-carbon fuel." –* ***M1***
>
> *"If the price of [current] fuel were to keep going up, obviously that would help incentivise people."* ***– M2***
>
> *"No early movers will be there unless there are compensation measures or incentives to use alternative fuels. For example, ammonia will cost five times the low sulphur fuel price. So the early movers, if they move without any compensation measures or any incentives, they will fail immediately." –* ***M1***

The participants' purchase decisions are based on the state of the market and what is required by the charter party. The responsibility to be efficient is split between the operator and the charter party.

> *"We have eternal research where we always model the market. And then when we see over the next year that you will have a deficit in the one or the other sector where we have the competency, we tried to build new ships to fill that gap because the expectancy is that the market will be higher than the usual." –* ***M1***
>
> *"The charter party agreements are our key to how the business operates. And the difference what is called the split incentive, I'm sure you've heard of it[…]you're sort of the guy who's letting out the hire car, doesn't care about the fuel efficiency, because the renter is paying for it. And it's that kind of split incentive. And so arguably, future arrangements would have some kind of shared incentive."* ***-M2***

4.1.4.3 Finance

To access finance from banks to procure a new ship, organisations need to demonstrate the emissions and carbon cost and provide an environmental case to support the purchase. This means it is more difficult now to access finance unless there are low carbon elements to the ship, such as supporting low carbon technology or an alternatively fuelled vessel. However, given the longevity of the asset, it might be a while before this impacts the carbon output of the current fleet.

> *"Access to finance from banks and loans, if you've got a green design or a low emission ship, is quite simple. Most of the banks are offering that at the moment. But then you need your deposit to put down your initial outlay." –* ***M3***
>
> *"The financing nowadays is becoming more and more complicated…you have to have a full disclosure of your emissions…without that, the finance will become much more complicated."-* ***M1***
>
> *"Emissions and the carbon footprint, in the future, will become one of the highest criteria for a serious financing corporation to consider, for giving financing for new builds or even use tonnage." –* ***M1***
>
> *"Many companies do have green statements on their website, and they have green policies, and they have to follow them. And I think it's part of the financing structure these days as well and related to bank loans."-* ***M3***

4.1.4.4 Energy-saving technologies

Participants reported that operators currently have measures to decarbonise involve adopting energy-saving techniques to lower overall carbon output rather than adopting a low carbon vessel. For example, optimising speed, hull and energy recovery through Kinetic Energy Recovery Systems (KERS).

> *"There are a lot of other ways to do it, either degrade the engine or add additional energy-saving equipment, but this is much higher cost instead of implementing a power limitation on board, to keep your ship sailing on a limited speed and comply with the relevant carbon intensity." -****M1***
>
> *"[In the past five years] optimisation of the hull and the energy balance that has been done and the recovery of energy lost, like kinetic energy recovery, heat energy recovery, using LED lamps for everywhere in the accommodation. All this contributed towards having an average of 32 to 33% reduction the emissions versus the ships built and delivered before 2014."-* ***M1***

4.1.4.5 Technological readiness

Some alternative fuels to power vessels are under development, but each alternative has some limitations. Hydrogen is difficult to transport given the low-temperature storage requirements. Nuclear reactors are very expensive to maintain, and there is some safety concern around the use of ammonia. However, given what has been discovered through early trials, ammonia produced from hydrogen seems like the most suitable option once initial barriers are overcome.

> *"If you go to hydrogen, which is one step before, you get it from the water; then you have the problems of storage because you need minus 353 degrees whereas ammonia you need only minus 35 degrees to keep it in store." –* ***M1***

> *"Most of the research now is done on ammonia because it's easier to transport, and you only have to consider how to deal with the fact that it is toxic."- **M1***
>
> *"Ammonia is a very widely transported cargo. So, it's not like ammonia isn't being transported at the moment. I can't give you the number, but I think there are about 18 million tonnes of ammonia made every year, and much ammonia is traded as cargo or as a commodity on ships. So, to burn it in the engine compared to transporting it isn't a massive step." – **M2***

The cost of alternative fuels is currently very high. It was suggested that synthetic fuels might be developed in the future to overcome the barrier of cost, but this is just speculation, and development is not underway.

> *"My opinion is that in the future, we will have more synthetic fuels dropping because they're still going to be much cheaper than green ammonia, green hydrogen..." – **M2***

4.1.4.6 Low carbon vessels

Low carbon vessels are not yet commercially available. There is some early research and development projects underway which are privately funded. However, trials of new vessels will cost millions of pounds. Some practical limitations have been uncovered by these research and development projects. For example, it has been found that hydrogen can only be used for short distances because it has a low energy density when stored as a compressed gas, and the cost of conversion from a regular ship to LNG is expensive.

> *"There are no zero-carbon vessels apart from the experimental ships at the moment, for any source of energy that is zero carbon." – **M1***
>
> *"Therefore, it might be easier to produce hydrogen, but it is more complicated to store it on shore and on board. And then even if you have the production, the infrastructure for supplying to the major hubs is not there, it would take maybe 10-15 years." – **M1***
>
> *"The technology is not there unless you invest several million for development and design. And then you go out with a prototype ship, but it doesn't mean anything." – **M1***
>
> *"The tanks for carrying LNG are much higher priced than the ammonia. So, one thing is for sure: with some investment, LNG engines can be converted to burn ammonia. It's not the easiest process, but you can do that." – **M1***

4.1.4.7 Timescales

There is an expectation that significant changes in low carbon shipping will emerge in around 15 years, with a shift toward ammonia fuelled ships and possibly some LNG. Ships have a pretty long lifespan, but participants reported that this is constantly reducing, particularly as new technologies emerge. Safety regulations would also need to be developed to support the technology, and this typically takes a long time.

> *"LNG will determine the future by 2035, you will start seeing some biofuels in 2037, you will see ammonia gaining grounds, with remaining some electricity and some*

*biofuels in operation, and the perception is ammonia is the most suitable fuel for decarbonising shipping." – **M1***

*This [lifetime of asset] is consistently reducing, in the future the lifecycle will be 20 to 21 years. Because exactly of the change of the technology." – **M1***

*"The difficult thing is, you can't buy the ships because nobody knows what ships to build or offer."- **M2***

4.1.4.8 Capacity

The operators noted that it is beneficial to transport more cargo in one ship to increase the efficiency of the operation. Hence, a consideration when choosing a new vessel is the capacity.

*"Efficiency doesn't mean only less consumption. But based on the fact that quite a number of ships are restricted[…]if you want to remain within the parameters, where in an area you're to trade are required, then the aim is to enhance the capability of the ship to transport more cargo." – **M1***

4.1.4.9 Geography/ infrastructure

As ships are used internationally, the technology to dock and refuel ships has to be compatible with ports worldwide. However, there is no low carbon solution which would suit all maritime freight operations. Different types of cargo have different requirements, which adds complexity to installing solutions in multiple locations.

One participant moves cargo ships and noted that, with this operation, speed is not an important factor, and the ships do not have strict schedules. In contrast, other operators have to move quickly and meet strict deadlines. This means that there is a relationship between the type of cargo and the decision for procuring low carbon vessels. Different technology would also be applicable to meet the needs of these different operators.

*"It would depend on how far the ship has to sail, whether it was an ocean voyage or a near-coastal voyage. The design of the ship would be different for different trading areas; the building requirements will be different." – **M3***

*"Bigger ships usually do longer journeys in some ways, and usually go slower [even if they can go faster]." – **M2***

*"Our ships sail around the world a lot slower, and we arrive when we arrive depending on weather and charter party conditions. However, other types of ships have a schedule to meet. This is extremely important that they arrive on schedule. So, there are different criteria based on cargo or ship size or type." – **M3***

As ships are used internationally, the infrastructure has to be integrated globally, with the ability to refuel at every port.

*"The problem is, who will supply ammonia and whether the infrastructure for an entire worldwide supply will be there." – **M1***

*"So, you get your hydrogen ship, but you can't refill it; there's no refilling in Rotterdam or Singapore or the Middle East. And that's the big challenge." – **M2***

There are three main types of shipping freight: dry bulk, wet bulk, and container ships. Each has different requirements in terms of speed, geography and infrastructure at ports. Whilst some research is being done to find appropriate solutions. Generally most shipping companies are not focused on decarbonisation at this point, and many operate old ships.

> *"If we analyse the three major types of ships, which account for maybe 80% of the cargo, which are the dry bulk, the wet bulk which are the tankers and liquefied gases, and the containers[…]all these ships they have their geographical area where they can operate, and the need of certain sizes, because of the size of the country, the population, the infrastructure of the ports, and the distances to carry." –* ***M1***
>
> *"Most companies out there trading around the world have got older fleets, older ships, and maybe they've got different mentality to what we have. So probably the responses you're getting from us today are different to the average response you would get from a wider sector of shipping companies." –* ***M3***

4.1.4.10 Bulk cargo

Bulk cargo ships are not under pressure to complete jobs quickly, and they do not operate to a strict schedule. One way to reduce carbon is to operate these ships at even lower speeds, even if the ship is capable of higher speeds. This is not a problem operationally and offers a more straightforward solution to decarbonise the operation than acquiring alternatively fuelled ships.

> *"For the dry and wet bulk cargo, the speed is not of the essence. A vessel ship can sail between 10 and 15 knots, and in most of the cases you reach the deadlines." –* ***M1***

4.1.4.11 Container vessels

Container vessels are much more time-sensitive; they need to travel at higher speeds because they carry high value, time-sensitive goods, and therefore more carbon-intensive as carbon emissions increase with speed.

> *"Container vessels, for instance, have a schedule and a time when they have to be in the port and a slot to deliver the cargo. So, it's more critical on those types of ships to perform."-* ***M3***
>
> *"The emissions of a container ship are much higher because they normally sail with higher speed."-* ***M1***

4.1.4.12 Staff knowledge

An additional consideration is that new technologies will require staff retraining across the whole supply chain, including training or recruiting specialist engineers. There are time and cost implications associated with widescale training, which means adopting low carbon vessels is a more complex consideration than just purchasing a new ship.

> *"We're looking at these electric ships now, and there's a lot more reliance on electrical knowledge. And with our older fleet, they have diesel or heavy fuel engines. And the knowledge, a chief engineer for one of those ships would struggle with when he went on a newer ship with many electronics on board." –* ***M3***

4.1.4.13 Policy

There is little motivation for maritime freight operators to invest in decarbonisation, and any progress toward doing so is slow. Putting regulation in place which stipulates that operators must reduce their carbon footprint would be a catalyst for change. Without such regulation, very few operators will consider low carbon options. It is expected that some decarbonisation regulations will be in place by June 2022.

> *"Regulation is necessary to make things happen because it's not happening at the rate of speed that we need it." –* ***M2***
>
> *"Now, the correspondence group of the IMO (International Maritime Organisation) is working towards developing the CII Rating [operational carbon intensity achieved by the vessel] and how to measure all these parameters. This will have a direct reduction of about 14-15% of the emissions because every ship should comply with that; it is a regulation which is the first step towards lowering the carbon emissions, the carbon footprint with the existing technologies, which is a critical step forward." –* ***M1***

4.1.4.14 Company policy

Participants reported a little pressure from customers to decarbonise the supply chain. However, shipping is already very efficient compared with other freight, so this won't be a driving force for development.

> *"The corporate social responsibility, so the people whose cargo is being moved, clearly want to show their supply chain, their lifecycle is low carbon." –* ***M2***

4.1.4.15 Shipping regulations

Providing an efficient ship helps to win a competition, even before it is required by regulation, so some operators are already exceeding the current carbon reduction targets. The International Maritime Organisation (IMO) dictate what the emissions reduction targets are. However, the participating operators are already ahead of these goals. The IMO is calculating carbon intensity indicators to measure the impact of ships. Despite the participating operators already adopting measures to lower carbon, they believe the industry needs a push by regulation to decarbonise. Currently, fuel cost is low, so there is little incentive to change, and operators will only change when regulations force them to.

> *"The energy efficiency design index requirements are there[…] if you can make sure that your ship is energy efficient, you're basically in and future-proofing it somewhat to comply with future outcomes…it's improving the long-term value of the vessel when it's competing with other vessels for trade." –* ***M2***
>
> *"We have some ships, which we built eight years ago. And we've done EEDI (Energy Efficiency Design Index) calculations on those ships. Before they were a requirement, but we will already notice, a few years down the line that people are asking questions about how efficient ships are, maybe three to five years ago, they weren't particularly interested" –* ***M3***
>
> *"Ship owner-operators don't change unless regulations make them do so."-* ***M2***

> *"It's like we need a stick, not a carrot. So the regulations which are going to come in the IMO in 2023-24, which we'll have to wait and see because they're historically the IMO is slow to do anything."* – ***M2***

For any new technology being deployed as part of the maritime operation, the safety of life at sea regulations (SOLAS) would need to be developed to regulate its use. SOLAS regulations have not been developed for any alternative fuel to be used commercially.

> *"SOLAS is not there yet. SOLAS should describe exactly the safety measures to be taken. We don't have experience sailing on hydrogen sailing or ammonia, where one is non-toxic but is difficult to manage to keep it under that conditions the other one is toxic ammonia, so we don't have SOLAS requirements."* – ***M1***

4.1.4.16 Energy efficiency

Shipping is already an efficient means of transport compared to other modes. In terms of alternative fuels, biofuels still produce emissions, and the greenhouse gas savings of LNG are minimal at around 10%. That means that adopting the alternative fuels currently available would have little impact on the environmental credibility of the company, which is already beneficial compared to road transport emissions.

> *"[Biofuels] are not environmental enough."* – ***M1***
>
> *"The carbon efficiency of moving one kilogramme from China to Southampton is probably still a lot more efficient than moving it from Southampton to London."* – ***M2***

However, customers are increasingly interested in how carbon-efficient the ships are. The operators can advertise their green credentials in their mission statements. Therefore, it is important for these operators to demonstrate their energy efficiency, which has been a driver for some of the developments they have adopted to date.

> *"If people know your ships are efficient, they're going to choose your ship over a ship which isn't as efficient in the long term."*- ***M3***
>
> *"If you talk about low carbon ships and the range and the availability of fuels as well, the efficiency becomes the top of the agenda."* – ***M3***

Table 4.7 Summary of the enablers and barriers for maritime freight

Barriers	Enablers
• **Alternative fuels for shipping are very expensive** • **There is little motivation to invest in decarbonising the maritime freight sector, costs are high, and there are few alternatives** • **Suitable low carbon ships are not commercially available**	• Shipping **regulation** focusing on decarbonisation would be a significant catalyst for change • Pressure from **customers** to decarbonise would spur development

Table 4.8 Changes over time in the maritime freight industry

Past: 5 years ago	Today	Future: 5 years from now
Decarbonisation was not a priority	Energy efficiency measures are being implemented by some early adopters Some private trials of alternative fuelled vessels The IMO has targets for reducing emissions	Decarbonisation measures stipulated in shipping regulations More research being conducted into suitable alternative fuels

4.1.5 Priorities across all sectors

It was evident in the focus groups that decarbonisation is a burgeoning area of discussion across all modes of freight transport. However, some sectors are further ahead on the timeline to decarbonisation than others. Development toward decarbonisation has been driven somewhat by government priorities, customer expectations, and somewhat by the operator's ambitions to capitalise on the benefits of being an early adopter of low carbon technology.

Participants were asked to consider all the factors involved in their decision-making process when procuring a new low carbon vehicle. In each group, the participants used Mentimeter to rank the importance of the criteria to generate a list of priorities for decision making for the sector from one to five, with one being the most important. Mentimeter aggregated the results to give an overall ranking for the group. Some criteria were identified across all sectors as an important consideration, such as the whole life cost of the asset, which was a priority for all the sectors. In contrast, other factors were specific to the sector, such as charter party requirements in maritime freight.

Each of the priorities identified as being in the top-five decision-making criteria is discussed to see how each factor is enabling or restricting advancements in decarbonisation in each sector, based on the insights gathered in the focus groups. It will also be considered why priorities vary across the four sectors.

The top priorities identified during the focus groups' ranking exercise are in **Table 4.9**, with a score of 1 indicating this was the highest-ranking criteria of importance in that group.

Table 4.9: Top ranking decision-making criteria for low carbon freight assets identified during the focus groups

Rank	Road	Public Sector	Rail	Maritime
1	WLC	Infrastructure	WLC	WLC
2	Range	WLC	Policy	Charterparty Requirements
3	Payload	Funding	Infrastructure	Subsidy/incentives
4	Reliability	Suitability	Range	Efficiency
5	Infrastructure	Emissions	Capability	Range, Infrastructure

Note: WLC = Whole life cost

4.1.5.1 Whole Life Cost

Across all groups, whole life cost (WLC) was identified as an important consideration when deciding to procure a low carbon vehicle. Participants from each sector noted that they must calculate the WLC to justify the purchase decision.

It is possible for road freight operators and the public sector to calculate the WLC with reasonable accuracy as many low carbon vehicles are commercially available and are in operation. However, it was noted that the depreciation rate of the vehicles is an unknown factor that causes some uncertainty as many low carbon vehicles have not been in operation long enough to understand the residual value of the asset at the end of its lifespan. Any uncertainty in cost is significant for the road freight sector in particular. They operate with very low-profit margins and need to prove cost savings down to the last penny.

Currently, the cost of LNG is subsidised, making it a viable alternative to diesel for long-haul road freight operators. The cost of electricity is significantly lower than that of diesel, making electric vehicles a viable proposition for public sector fleets which contain more small vans. Whilst the upfront cost of a low carbon vehicle is more expensive than a diesel comparator, the lower fuel costs help the business case for procuring a low carbon freight vehicle in these sectors.

For the rail sector, the whole life cost of a low carbon rail asset was identified as an essential factor, but one that is not possible to calculate due to the immaturity of the market. It is anticipated that any modifications to reduce carbon would have significant associated costs as the rail infrastructure itself needs to be updated alongside any new asset.

Similarly, in the maritime freight sector, cost was identified as having importance. However, the whole life cost of low carbon ships is not yet fully understood. While some alternative fuels are under consideration, such as ammonia and LNG, the cost of these fuels is significantly higher than the diesel or HFO alternatives currently in use. Therefore, WLC may be a barrier to the adoption of low carbon ships in the maritime freight sector.

4.1.5.2 Infrastructure

Across all sectors, infrastructure was identified as one of the primary considerations when making a procurement decision. Lack of existing infrastructure and uncertainty about the availability of future infrastructure were considered barriers to adopting low carbon assets at this stage.

In the road freight sector, the operators in the focus group were long-haul operators and considered LNG fuelled trucks as a suitable solution for their operations. Innovate UK's 2019 Low Emission Freight and Logistics Trials (LEFT) found that the well-to-wheel (WTW) greenhouse gas emissions of LNG HGVs for long-haul duty cycles were between 16% - 75% (depending on standard BEIS factors or renewable energy factors) lower compared with a similar diesel vehicle on the same duty cycle. The operators in the focus group had geographically diverse networks of operation across the UK, with many operating in rural Scotland. In such areas, the LNG refuelling infrastructure has not yet been deployed, which is a barrier to adoption. There is a paradoxical situation occurring, where operators will not procure LNG vehicles until the infrastructure is in place. However, fuel suppliers will not install infrastructure until there is proven demand for the supply. In other areas of the UK, infrastructure is more widespread to support the refuelling of LNG vehicles. In these locations, low carbon vehicles are becoming more commonplace.

The public sector identified infrastructure as the primary consideration in decision-making. Moreover, the local authorities feel that they have a responsibility to aid in deploying infrastructure to support the uptake of low carbon vehicles across all road transport. There was preference across the group for an infrastructure model accessible to all, such as a forecourt design for EV charging hubs instead of private charging facilities and on-street charge points. This would enable wider uptake of electric vehicles both for private vehicle ownership and freight, removing the barrier of access to recharging facilities.

The public sector is making the most progress in removing the barrier of access to infrastructure. Local authorities are investing in the installation of their own refuelling infrastructure to support hydrogen uptake in public sector fleets.

For the rail sector, any adoption of low carbon rail assets relies on the infrastructure first being in place. Until there is certainty on what infrastructure will be deployed, the operators cannot make purchase decisions. However, it is integral to the operator's choices in the long term.

Infrastructure requirements for the maritime freight sector are complicated by the industry's international nature, meaning any vessel has to be compatible with ports around the world. As low carbon vessels are still in the early development phase, no solution to this barrier has yet been identified. However, an added complexity is the variance in requirements across different types of freight cargo.

4.1.5.3 Range/ payload

Closely aligned with infrastructure requirements is the asset's range capability, which also feeds into the efficiency of the operation as a whole. With greater range, there is reduced downtime required for refuelling or recharging. Therefore, less anxiety is associated with lack of infrastructure. The range was identified as one of the top priorities by the road, rail, and maritime freight sectors. Similarly, payload determines the amount of freight that one vehicle can move and is aligned with range, given that increased payload will decrease fuel efficiency, thereby reducing the range. The road freight participants ranked payload next to the range in the decision-making criteria.

For the long-haul operators in the road freight sector, the range was the second-highest priority, followed by the payload. The operators move freight for long distances and often with double shift vehicles, meaning that any downtime for refuelling reduces their operational efficiency. For this reason, electric vehicles were considered unsuitable, even if payload capacity was increased due to the time required to recharge the vehicles. The range capacity of low carbon vehicles is considered to have improved over the past five years; therefore, this is not seen as a significant barrier to adoption, though the low carbon vehicle options available to them that would be capable of the range they require may be limited. It was noted that the operators could make a greater profit by delivering more goods in a single trip therefore, low carbon vehicles must have the same payload capacity and the addition of energy-saving technologies does not add significant weight to the vehicle.

The public sector participants did not identify range as a top consideration when purchasing vehicles. This can be explained by the small area in which each public sector fleet operates and the limited mileage that the vehicles are likely to undertake in one day. Similarly, the additional weight of batteries was not of concern as these operators rarely meet payload capacity.

The range and weight requirements for rail freight are considerable, and at the moment, these requirements can only be met by diesel-fuelled trains. Electric locomotives can also deliver range and weight requirements, but limited by the extent of the electrified network. As well as the asset, infrastructure would need to be upgraded to support heavy axle loads to allow heavier freight trains access across the whole rail network. Investments in battery technology could help accelerate developments. However, the range is a requirement that cannot be met with any low carbon rail solution currently under development.

For the maritime freight sector, the range is an important requirement. They need to transport goods long distances without the opportunity to refuel. Given the technology's immaturity, it is not clear which alternative fuel will offer the range and payload capacity required. Therefore it is not known if this will be a barrier to uptake.

4.1.5.4 Policy

The rail industry group identified policy requirements as a key decision-making criterion. Whilst the other sectors did not identify this as one of the top five considerations; it is understood that all procurement decisions are made within the context of what policy dictates, and there was a common trend through all the focus groups that each sector felt a lack of policy direction was inhibiting decision making.

This was a particular concern for rail freight, given the longevity of the rail assets. There is risk in investing in technology which will not be supported by the policy in the long term, as the rail assets have a lifespan of up to 35 years. Therefore, the rail freight operators are reliant on policy direction to inform the decision-making process

4.1.5.5 Charterparty requirements

Charterparty requirements are a decision criterion specific to the maritime sector. These are the requirements dictated by the customer, which specify the freight to be moved, the timescale, and the type of vessel. The charter party may dictate that a low carbon vessel is preferred. The charterparty requirements would drive the decisions to procure low carbon vessels. Therefore, it is an important decision criterion for those operators.

The road freight sector also noted in the discussion that customers' requirements play a part in encouraging the uptake of low carbon vehicles, particularly with customers looking to decarbonise their supply chain. Therefore, it is advantageous to adopt low carbon vehicles in the road freight sector, but this is not a top-ranking criterion for these operators.

4.1.5.6 Subsidies, incentives, and funding

The maritime freight operators included subsidies and incentives as a top decision criterion for procurement decisions. The public sector participants ranked funding as a top decision criterion. These criteria dictate the need for external revenue to support the adoption of low carbon assets, and it was noted that this funding should come from the government given that the freight industry needs to adapt to the decarbonisation agenda

While the road freight sector noted that incentives and subsidies would increase the uptake of low carbon vehicles, this did not rank a top priority.

The public sector noted that funding would be required to support the rollout of necessary infrastructure before low carbon vehicles become widespread. Some funding is available from the government to support the upfront cost of vehicles. Given the public sector’s role in supporting infrastructure installation, this was a key consideration for this group.

The rail sector is at an early stage in the development of low carbon rail options (other than overhead electrification). So, the consideration for incentivising uptake may not be as applicable here. However, it was noted that what little funding the sector has for trials has come from private investors rather than the government.

That subsidies and incentives ranked as a priority for the maritime sector could be due to the current cost difference between alternative fuels and currently used fuels like diesel and HFO for shipping. Under considerations for WLC, the maritime operators cannot justify the procurement of an alternatively fuelled vessel due to the cost difference. Therefore, subsidies and incentives to adopt low carbon fuels would be required for it to be a viable decision for the procurer.

4.1.5.7 Reliability

Reliability was an important factor for consideration in the road freight group. However, it did not appear in the top five priorities for other sectors.

The road freight operators indicated that low carbon freight vehicles are considered less reliable than their diesel comparators. However, they suggested that reliability was improving over time. Still, given that the road freight operators indicated that minimising risk in a purchase is important, the reliability of the vehicle must be demonstrable as any downtime due to breakdown or maintenance will cost the company. Moreover, many regular garages are not equipped to service alternatively fuelled vehicles, which could cause further disruption in the event of a breakdown. Given the wide geographical networks of the road operators, these vehicles are more likely to operate in remote locations where it is more challenging to access assistance. This could explain why reliability is a higher priority for these respondents than other groups. Operators would need to see evidence of low carbon vehicles' reliability compared with diesel to inform a procurement decision.

4.1.5.8 Efficiency

Efficiency was identified as a top priority for consideration by the global shipping operator in the maritime freight sector. Its absence in the top criteria in other sectors could be explained by the fact that fuel efficiency is a factor which feeds into the WLC calculation rather than as a stand-alone criterion. However, for this operator, the efficiency of the low carbon vessel was considered to mean the ability of the vessel to move freight at a speed which meets the time restrictions of the charter party and has the payload capacity to move large amounts of freight in a single journey. The ability of the vessel to meet these efficiency requirements is a key consideration of this operator.

4.1.5.9 Suitability

Suitability was included as a priority for the public sector group. However, it did not appear in the top five priorities for other sectors. Identifying a suitable vehicle was a challenge for these operators.

The public sector group tend to operate mixed fleets of vehicles, including small vans and large refuse collection vehicles. The needs of the operators depend on the specificities of their locality, including area geography, existing infrastructure, congestion issues or rurality. Therefore, there is no simple vehicle solution across different local authority areas or within one local authority fleet. With multiple factors under consideration and multiple approaches needed, plus additional considerations for installing the associated infrastructure, it is clear that the public sector does not feel equipped to understand which low carbon technology is suitable for which task. It was noted that the picture is likely to become clearer over time, but currently, identifying a suitable low carbon vehicle is a challenge. With suitability to task noted as a top priority, greater understanding is needed of the advantages and disadvantages of adopting particular low carbon technologies to aid an informed choice.

4.1.5.10 Capability

The rail freight group listed capability as a top priority for consideration when procuring a low carbon rail asset. This did not appear in the top five priorities for other sectors but is linked closely with range, payload and suitability, ranking as decision-making factors across the other groups.

Due to the immaturity of developments in low carbon rail, participants noted that no viable solution has emerged which has the same capability as diesel. Whilst diesel-powered rail can deliver the speed, payload and range required for moving large amounts of freight, there are limitations in the capability of other powertrains to deliver the same merits. Electric powertrains are the most promising alternative, but the weight of batteries reduces the payload of freight carried. Another alternative would be hydrogen, but there is no route where this can be deployed, so it is too early to understand the capability enabled by a hydrogen powertrain. As capability is a top priority for the rail freight industry, this could be a barrier to low carbon rail stock uptake.

4.1.5.11 Emissions

The public sector group was the only sector to list the potential emission savings of the low carbon vehicle as a priority in the procurement decision. Whilst other groups acknowledged the environmental advantages of a low carbon asset as beneficial, this was not listed as a priority consideration.

Many local authorities in the UK have declared a climate emergency. In response to this, they have set ambitious targets to decarbonise their own operations and lower emissions and carbon. These operators, therefore, need to ensure that the vehicles they procure are in line with these objectives. Moreover, in the past five years, the public sector has been focused on improving air quality, particularly in the UK's urban areas. The introduction of low emission zones and clean air zones in UK cities considered emissions precedent.

A switch toward the decarbonisation agenda may move priorities away from tailpipe emissions and toward the carbon output of the well-to-wheel energy use. However, nonetheless, emissions savings will remain a consideration for the public sector.

The private sector is not under the same pressure to decarbonise their operations, and purchase decisions are motivated more by making a profit in their businesses by operating efficiently. For the public sector, there is some uncertainty around which technology will offer the best solution in terms of carbon savings. However, as technological developments in low carbon vehicles improve, it is not expected that environmental targets will be a barrier to adoption.

4.1.5.12 Summary of progress to decarbonisation across the freight industry

The public sector is seemingly the most advanced in its progress toward decarbonisation. This is partly due to the nature of the operation, which utilises comparatively smaller vehicles for shorter trips, which are well suited to the low carbon vehicles commercially available. This, combined with ambitious targets to lower emissions and decarbonise local government operations, has accelerated the uptake of low carbon vehicles in this sector. Some barriers remain, high on the priority list of considerations when procuring low carbon freight. Specifically, the installation of infrastructure to support low carbon vehicle recharging and refuelling is a barrier; this can be overcome by a clear indication from the central government about the preferred route to decarbonisation (whether that be electric, hydrogen or an alternative), uniformity in the approach to charge points and payment mechanisms, and funding to help implement the infrastructure. An additional barrier is the suitability of technologies to meet the diverse needs of public sector fleets; this will be overcome with further development of vehicle technology and more demonstrable results from low carbon vehicle trials.

The road freight sector has also demonstrated some progress toward decarbonisation, with the development of lower-carbon fuelled vehicles for long-haul freight operations. However, uptake is somewhat slower than desired as there is an element of risk associated with adopting alternative vehicles. The road freight sector operates with very low-profit margins, and the cost of a vehicle is the topmost priority when considering procurement. Currently, the factors which could impede the operational efficiency of the road freight operators are a barrier to uptake; this includes any deficiency (compared with a diesel vehicle) in range and payload, which mean fewer goods can be moved in a single trip, the unavailability of refuelling infrastructure or any failing in reliability. To consider the adoption of low carbon vehicles, the shift would need to be incentivised in some way by the government, or be made compulsory by a policy which forces all operators to move away from diesel, thus allowing a level playing field where no operator loses their competitive edge over a competitor.

Progress toward decarbonisation in the maritime freight sector is significantly behind road freight. However, some advancement has been achieved through incremental adaptation of a range of energy-efficient design measures, rather than the adoption of alternatively fuelled vessels which is not anticipated shortly. The main barrier here is the identification of a suitable alternative which offers the same efficiency and range and is cost comparable when benchmarked against a model ship. Such an alternative has not been developed yet. An additional barrier which is unique to the maritime sector is the requirement for suitable infrastructure for docking and refuelling to be uniformly available internationally, which will require a joined-up approach across the international shipping industry.

The rail freight sector has perhaps seen the smallest progress in decarbonisation. In part, this is explained by the fact that the sector is already a relatively low carbon means to transport goods. So there is far less potential for significant improvements. Therefore the sector has faced less pressure to demonstrate decarbonisation measures. Nonetheless, the operators in the focus group shared ambitions to improve the environmental impact of their operations, and Network Rail has set ambitious targets to reduce carbon emissions which the rail sector must adhere. The main barrier in this endeavour is technological development; no suitable solution, other than extensive overhead electrification, has been developed which can move freight as efficiently as diesel trains, and rail assets cannot be adopted before there is a network of infrastructure already in place to support them. Moreover, given the longevity of a rail asset, the operators require indication from the government that rail freight will be supported in the long term. Capability and policy are top priority factors for the rail freight sector, so these barriers must be overcome before further progress toward decarbonisation is achieved.

4.2 Analytic Hierarchy Process (AHP)

During the focus groups (section 4.1), several drivers influenced a freight operator’s or owner’s decision to procure low carbon technologies or procedures. The most important criteria were adhering to regulation, reducing operating costs, compatibility with the infrastructure, reliability, contractual obligations, and technology readiness level. Although the main objective is to examine ways to reduce GHG emissions, the importance of cost or reliability is likely to be more significant for some operators. These drivers were further investigated using the AHP method to evaluate their significance. The final results of each focus group are presented in the next section. The weights derived for each sector are presented in the following sections, followed by a thorough overview of their compared results.

4.2.1.1 Road Freight

The highest priorities for the road freight operators were Whole Life Cost (WLC), range, payload, reliability, existence of recharging or refuelling infrastructure and driver's comfort or/and facilities. Six out of the nine participants responded to the AHP pairwise comparisons. The final weights of the road freight criteria are presented in **Table 4.10** and Figure **4.1** below.

Table 4.10 Weights of the most important drivers for the road freight decarbonisation

Criteria	Weight
Reliability	27.7%
Whole Life Cost	21.9%
Vehicle Payload	20.1%
Recharging/Refuelling Infrastructure	11.5%
Driver Comfort/Facilities	10.9%
Vehicle Range	8.0%

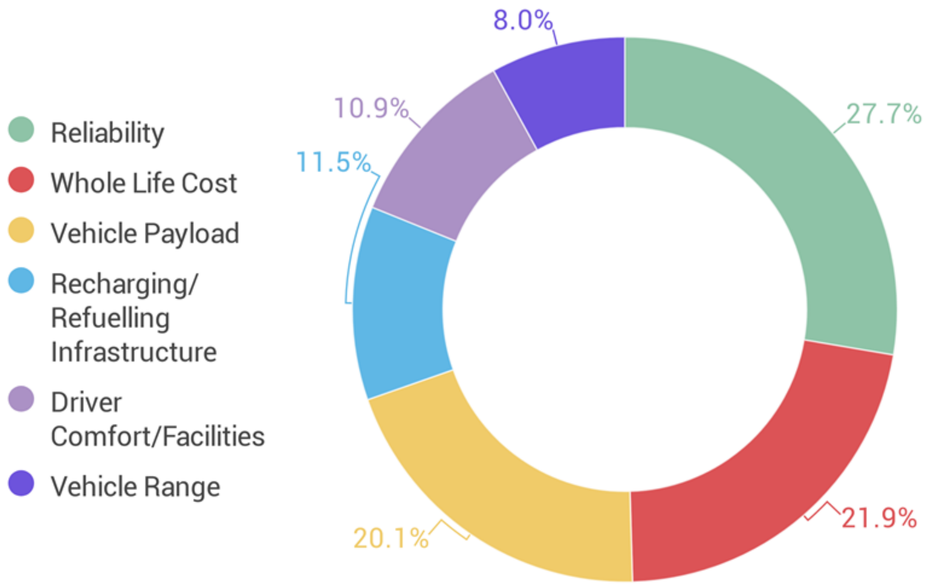


Figure 4.1 Weights of the most important drivers for the road freight decarbonisation

Reliability appears to be the most critical criterion in the decision making towards procuring low carbon vehicles or technologies, ranking at almost 28%. WLC and payload follow closely, ranking 22% and 20% accordingly. There is a big gap, of nearly 10%, between the three last criteria. The existence of recharging or refuelling infrastructure, the driver’s comfort and facilities and the vehicle’s range still play a substantial role in the decision making, scoring a mean of 10%.

The **group's Consistency Ratio (CR)** was **1.9%**, which is judged as very satisfying, indicating that the respondents understood the method and the approach.

The group’s **Consensus Indicator (CI)** was **52.1%**. The CI is not indicative of the research quality. Still, it is a measure of homogeneity of priorities between the participants. In this case, the CI is moderately low, indicating what can be seen in **Figure 4.2**. There exist two sub-groups between the respondents, one with individuals representing medium-sized haulage operators and one with individuals representing large haulage firms. The first group evaluates WLC as their highest priority when procuring low carbon vehicles or technologies. In contrast, the second group ranks higher in the reliability of those, given that a higher upfront cost is not necessarily a barrier if its reliability and payload are sufficient.

Further on, in **Figure 4.2** and **Figure 4.3**, recharging/refuelling infrastructure appears more critical for the large haulage firms, adding up to their willingness to increase their cost and procure low carbon technologies in trade of the essential infrastructure’s existence. On the other hand, the driver comfort/facilities criterion scores higher on the medium-sized hauliers. As they mentioned, this criterion is aligned more with the drivers' safety and, therefore, their easier recruitment.

Finally, the overall importance of reliability, WLC and payload is evident for the road freight sector as they add up to almost 70%. No matter the size of the haulage firm, this indicates that these factors should be enhanced, and the associated barriers eliminated to achieve a broader uptake of low carbon technologies.

For completeness, individual weightings are shown in **Figure 4.3** but are not discussed at the individual level.

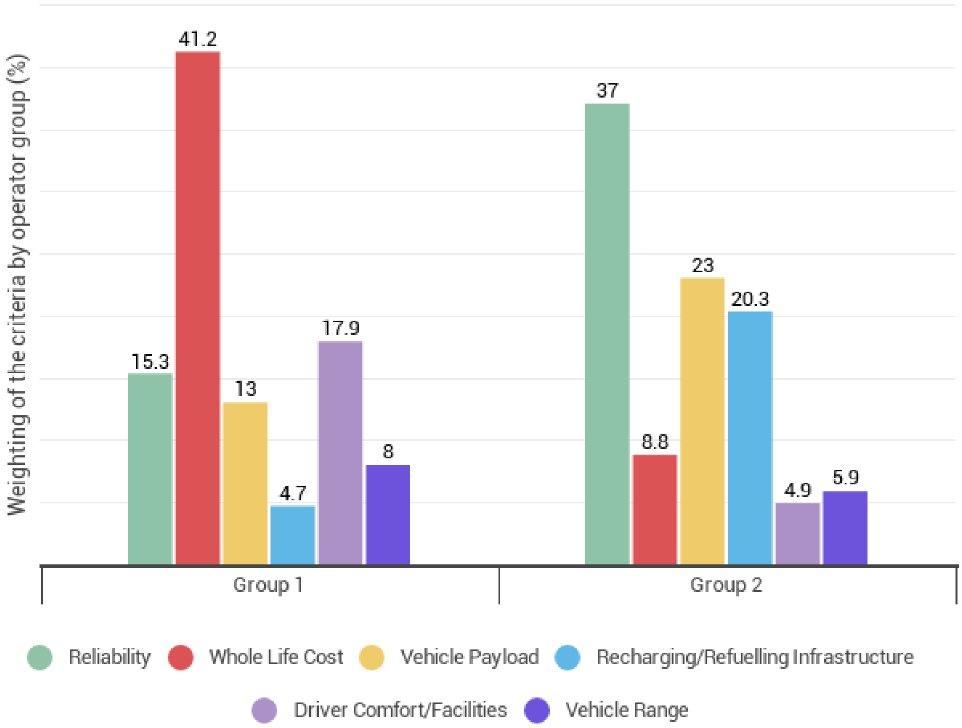


Figure 4.2 Weights of the road freight criteria by operators' group

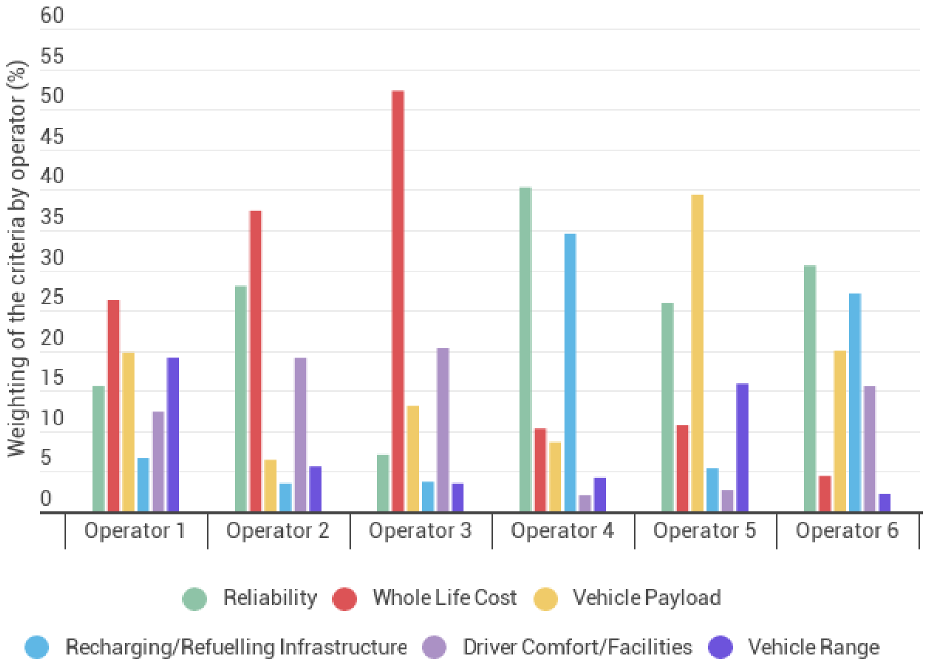


Figure 4.3 Weights of the road freight criteria by operator

4.2.1.2 Rail Freight

The top-ranked criteria for the rail freight operators were WLC, policy/government commitment, the existence of recharging or refuelling infrastructure, range of rolling stock, suitability for tasks and compatibility with the network.

At the AHP interviews, while discussing the criteria chosen with the participants, it was indicated that "compatibility with network" refers mainly to the geometrical characteristics, which are mandatory to proceed. Instead, "suitability for tasks" could better include the speed and weight, limitations that might occur when purchasing a low carbon locomotive. Therefore, we replaced "compatibility with network" with "reliability" as the AHP criterion.

Three out of the six participants responded to the AHP. The final weights of the rail freight criteria are in Table **4.11** and **Figure 4.4** below.

Table 4.11 Weightings of the most important drivers for the rail freight decarbonisation

Criteria	Weights
Whole Life Cost	22.8%
Suitability for Tasks	21.1%
Reliability	19.5%
Policy/Government Commitment	19.2%
Recharging/Refuelling Infrastructure	10.2%
Range of Rolling Stock	7.3%

Whole life cost appears to be the main driver for the rail freight sector, with 23%, closely followed by the suitability for tasks, with 21%. Reliability also holds a significant share, with 19%, while recharging or refuelling infrastructure and rolling stock's range follow last, with lesser weights of 10% and 7% proportionally.

The **group's Consistency Ratio (CR)** was the lowest of all the sectors, with **0.9%**, judged as very satisfying and indicating that the respondents approached the topic precisely. The group's **Consensus Indicator** (CI) was also pretty high, at 65%, indicating a good homogeneity. The respondents represent one of the largest rail freight operators, a rolling stock provider and a start-up company moving freight by electric rail. Therefore, some differences in their priorities and approaches are expected and can be seen in **Figure 4.5**.

For the large operator (2), recharging/refuelling infrastructure appears as a sub-part of the WLC; that's why it follows second. All factors are judged as mandatory, which explains why there are no significant differences in the weighting. The policy/government commitment was much lower weighted, although it was highly valued, they appeared concerned about policy consistency and government commitment over the years.

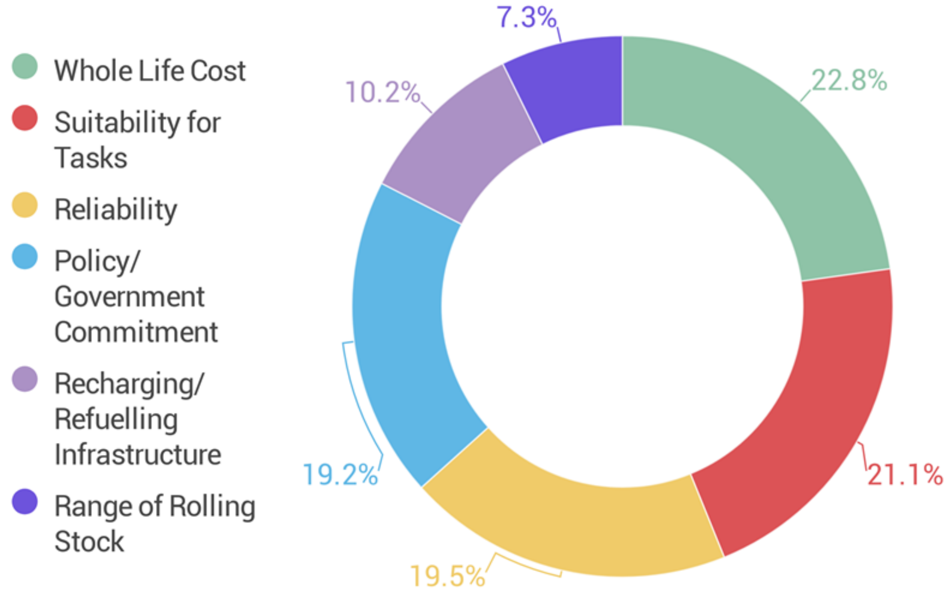


Figure 4.4 Weights of the most important drivers for the rail freight decarbonisation

There appeared to be three scales of priority for the rolling stock provider (1). The highest one is for the WLC aligned with the weight of the policy/government commitment (32%). Suitability for tasks and infrastructure make the medium-weighted group (13%), while the range and reliability follow with much lower weights (5%).

Finally, for the start-up company, reliability holds the greatest share of their decision-making procedure, with 44%. Suitability and policy follow, with 24% and 19%. Finally, range and infrastructure were weighted very low, with 3% and 2%, respectively.

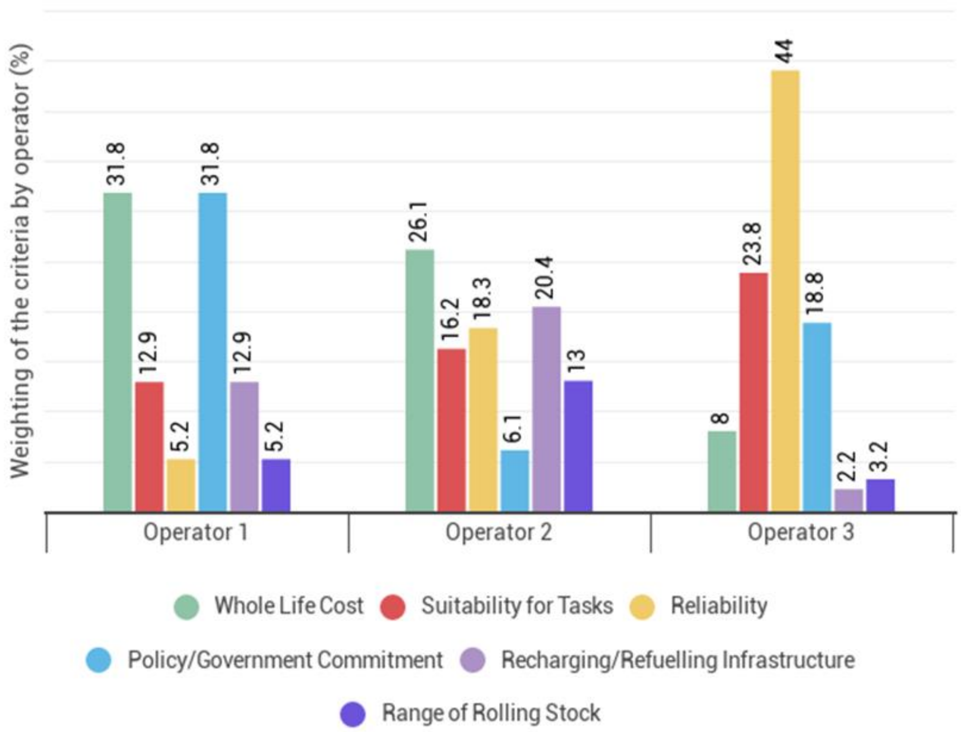


Figure 4.5 Weights of the rail freight criteria by operator

4.2.1.3 Maritime Freight

For the maritime freight focus group, the most important criteria were WLC, efficiency, subsidy or incentives, vessel range, recharging or refuelling infrastructure, and charter-party requirements. Two participants responded to the AHP pairwise comparison model. It should be mentioned that these top-ranked criteria of the focus group were also based on the two operators' responses, as they were the decision-makers. The final weights of the shipping freight criteria are presented in Table **4.12** and **Figure 4.6** below.

Table 4.12 Weights of the most important drivers for the shipping freight decarbonisation

Criteria	Weightings
Subsidy/Incentives	25.7%
Charter Party Requirements	25.0%
Efficiency	22.8%
Whole Life Cost	19.1%
Vehicle Range	3.8%
Recharging/Refuelling Infrastructure	3.6%

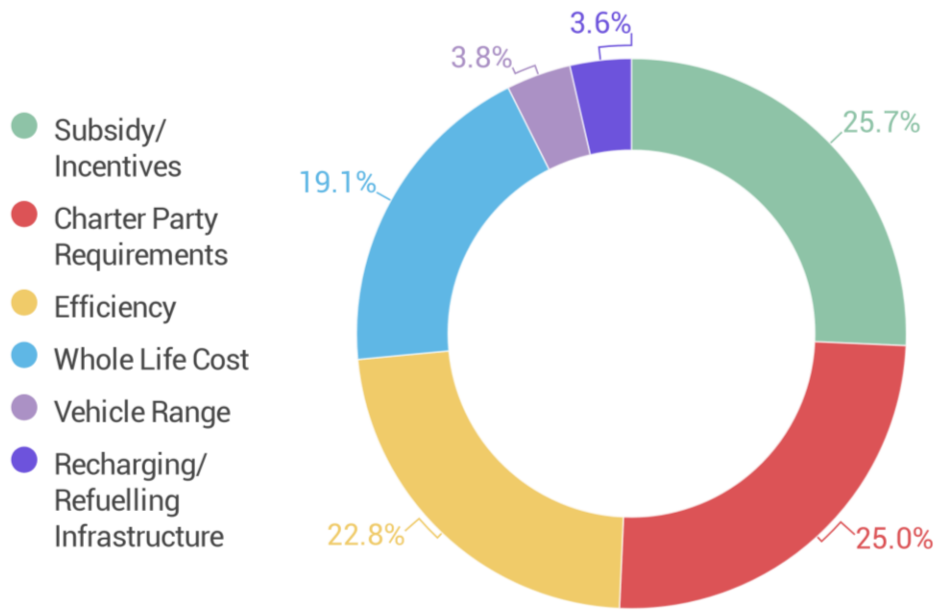


Figure 4.6 Weights of the most important drivers for the shipping freight decarbonisation

For the shipping freight sector representatives, subsidy or incentives, scoring 26%, very closely followed by the charter-party requirements, scoring 25%, appear to be the most important criteria for procuring low carbon vessels or relevant technologies. Efficiency follows with no significant difference as well, scoring 23%. WLC comes next with 19%. The vessel’s range and the existence of recharging or refuelling infrastructure appear to have much lesser importance in the decision-making procedure, with weights of around 4%.

The **group's Consistency Ratio (CR)** was **1.1%**, which is very satisfying for the small number of participants. The group’s **Consensus Indicator (CI)** was moderately high, at **65.3%**, indicating a good homogeneity level among the respondents. Given the fact that the two respondents represent different geographical scope and coverage, it was evaluated worthy to face them as two separated sub-responses. The first one is based in the UK and operates primarily around northern Europe. In contrast, the second is based in Cyprus and operates globally.

In Figure **4.7**, for Operator 1, WLC appears as the essential criterion in their decision making. For their company, efficiency is interpreted as part of the whole life cost, depending on the type of the contracts and the charter parties their shipping company has. They stated that depending on who charters the ship. Whether they have time limitations, efficiency can be considered a separate criterion, which does not apply to them. So, if the shipping company makes all the decisions, efficiency would be separated from the whole life cost. Still, because most of the decisions are affected by the charter parties, it is not valued as a different factor.

On the contrary, according to Operator 2, the vessel/new fuel/technologies' efficiency is the pre-required driver, which will lead them to purchase a low carbon ship. Following this, incentives/subsidies will complete and facilitate this decision. WLC, they stated, is something that does not differentiate much between procuring low carbon or other vessels; the subsidy is the one that might fill this gap. Finally, range and relevant infrastructure are of the same importance, and they could be considered a single factor/criterion. They will have to be in place before expanding in different geographical scopes. For them, low carbon operations will be much easier facilitated in near-shore shipping and further on in the development areas in Europe, North America, and Asia.

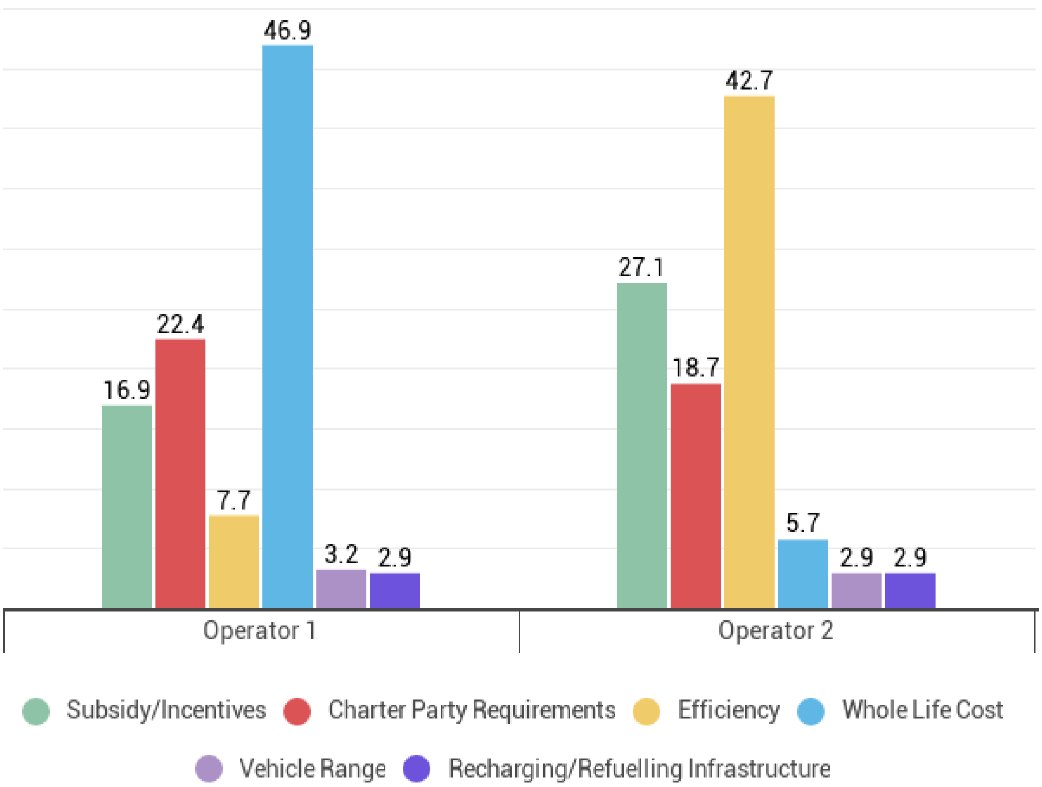


Figure 4.7 Weights of the shipping freight criteria by operator

4.2.1.4 Public Sector

The highest priorities for the public sector fleet operators were the GHG Savings, funding, governmental policy, WLC, suitability for tasks and the recharging or refuelling infrastructure. All six participants responded to the AHP pairwise comparisons. The final weights of the public sector fleet criteria are presented in **Table 4.13** and **Figure 4.8** below.

Table 4.13 Weights of the most important drivers for the public sector decarbonisation

Criteria	Weights
GHG Savings	26.1%
Funding	20.1%
Government Policy	19.2%
Whole Life Cost	14.2%
Suitability for Tasks	11.7%
Recharging/Refuelling Infrastructure	8.8%

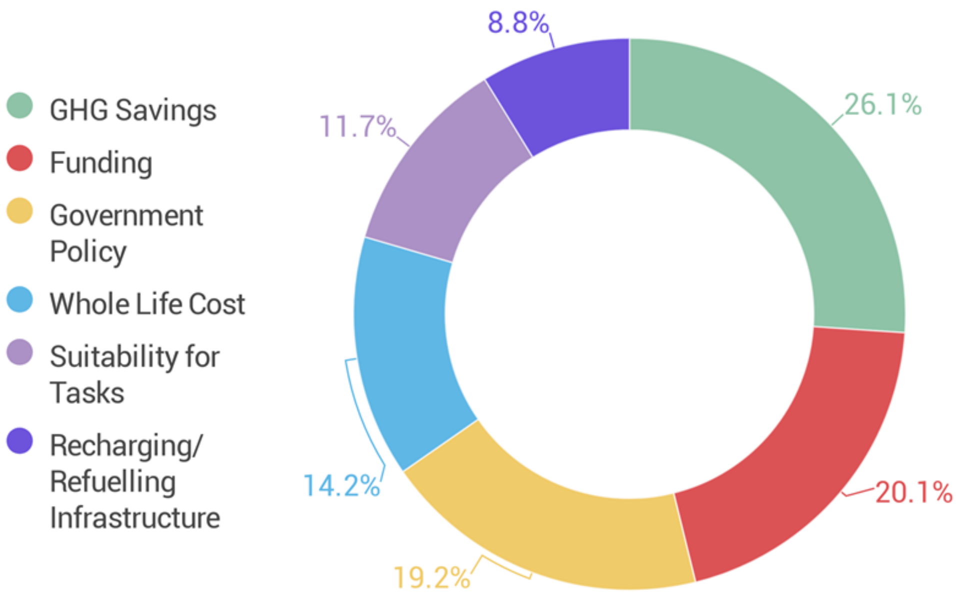


Figure 4.8 Weights of the most important drivers for the public sector decarbonisation

GHG savings appears to be the most critical factor towards procuring low carbon technologies with 26% weighting, as might be expected of the public sector to put public health before profit. Funding closely follows, with 20% weighting, then by Governmental Policy (19%), stating the direct influence on the Local Authorities' (LAs) decision-making. Finally, WLC, suitability for tasks and the required infrastructure's existence follow, with no significant difference between them. The first three criteria will show the way towards the low carbon procurement, and the three last ones will ensure its facilitation.

The **Consistency Ratio (CR)** of the group was **1.0%**, which indicates the participants' sound understanding and engagement with the method. The group's **Consensus Indicator (CI)** was **53.6%**. This moderately low CI states the trade-off between the top three criteria between the different local bodies, as presented in **Figure 4.9**. For the Local Authorities that do not procure vehicles but lease them (ex. Operator 5), WLC appears to have much lower importance. This applies to the rest of the LAs since the vehicles' procurement does not involve the "personal" risk, as in the operators of the other sectors.

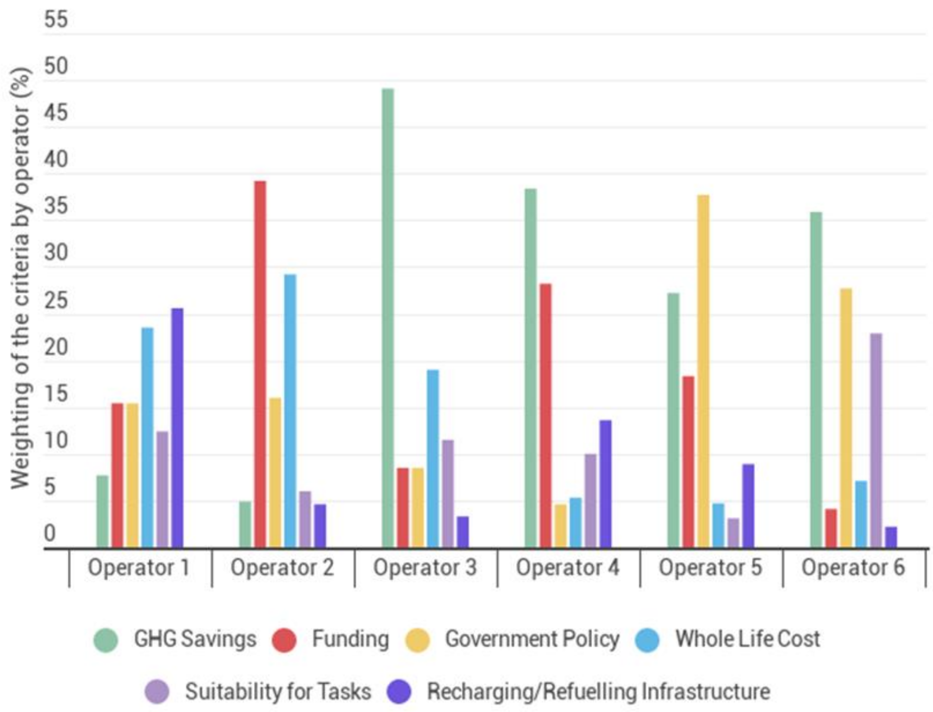


Figure 4.9 Weights of the criteria by local authority

4.2.1.5 Weights of the criteria across all sectors

A summary of the prioritised weights across all sectors is presented in **Table 4.14**. Although, the ranking of the criteria represents their importance. Still, to better understand their decision-making procedures, the proportional correlation between those criteria is the most indicative factor. The differences between AHP weights and the focus groups' rankings (**Table 4.9**) are discussed in section 4.3.

Table 4.14 Ranked weights of the criteria across all sectors

Rank	Road	Public Sector	Rail	Maritime
1	Reliability	GHG Savings	Whole Life Cost	Subsidy/Incentives
2	Whole Life Cost	Funding	Suitability for Tasks	Charter Party Requirements
3	Vehicle Payload	Government Policy	Reliability	Efficiency
4	Recharging/Refuelling Infrastructure	Whole Life Cost	Policy/Government Commitment	Whole Life Cost
5	Driver Comfort/Facilities	Suitability for Tasks	Recharging/Refuelling Infrastructure	Vehicle Range
6	Vehicle Range	Recharging/Refuelling Infrastructure	Range of Rolling Stock	Recharging/Refuelling Infrastructure

In the following **Figure 4.10**, **Figure 4.11**, **Figure 4.12** and **Figure 4.13**, the proportionate correlation between the most important criteria of each sector can be easier visualised by the relative font sizes used. In some sectors, all of the criteria are of almost equal importance. In others, there are some greatly prevailing ones.

Figure 4.10 Representation of the road freight sector weighted criteria

Given that the criteria are not the same across all sectors, more extensive conclusions cannot be derived. Still, some comments can be made for most of them.

Whole Life Cost, as expected, exists as one of the most important criteria in decision making across all sectors. In the rail sector, WLC is the most decisive criterion. Whereas in the road freight it was weighted as the second most important one. WLC is weighted as the most important criterion for procuring low carbon vehicles or technologies when taking a more thorough look at the road freight sub-group of the medium-sized hauliers. In the public sector, WLC is an important factor. Still, given that the local authorities' fleet operators are not involved in the financial risk, like the rest of the freight sectors, WLC is not weighted as highly.

Finally, the shipping freight sector operators consider the importance of WLC according to their geographical scope and their charter party contracts. Due to the type of contracts and cargo, the first operator valued WLC as the most crucial criterion, whereas the second operator did not value WLC as one of the most decisive factors. For the shipping freight sector, depending on the type of the operator, **efficiency** might incorporate the concept of WLC as well, which is why it appears to have a higher weight.

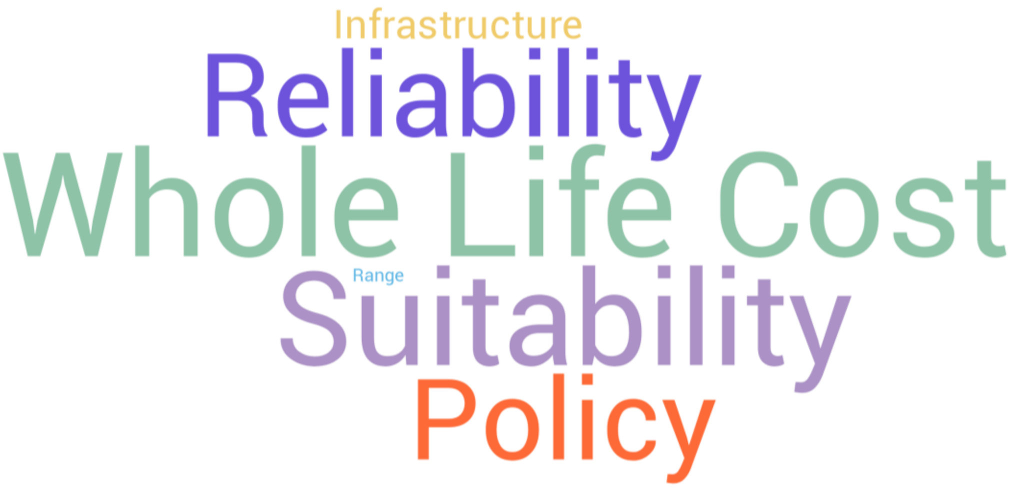


Figure 4.11 Representation of the rail freight sector weighted criteria

The existence of relevant **Subsidies** or **Incentives** and **Funding** appear as the highest priority to the shipping sector and the second highest to the public sector. The shipping freight sector operators did not consider WLC the highest decision-making priority. They were keen to procure low carbon technology and vessels as long as this trade-off existed with the subsidy. Therefore, they ranked their existence highly. On the other hand, the public sector can move forward in the procurement only as long as there is funding in place to allow it. That is why their representatives valued it high.

Reliability is, surprisingly, the most important driver for the road freight sector, surpassing WLC. This indicates that the road freight operators are willing to overcome the possible higher WLC resulting from purchasing low carbon powertrains if they feel safe about their reliability. In the road sector, matching the high reliability demonstrated by diesel and heavy fuel powertrains vehicles might be the most significant barrier to adopting alternative technologies.

Reliability is one of the most important drivers for the rail freight sector. Therefore, the same barrier faced by the road freight, concerning the perceived reliability of alternatives to diesel and heavy fuel powertrains, also applies to the rail freight sector. But in this case, the dilemma is more between the familiar and known against the unknown and untested technology.

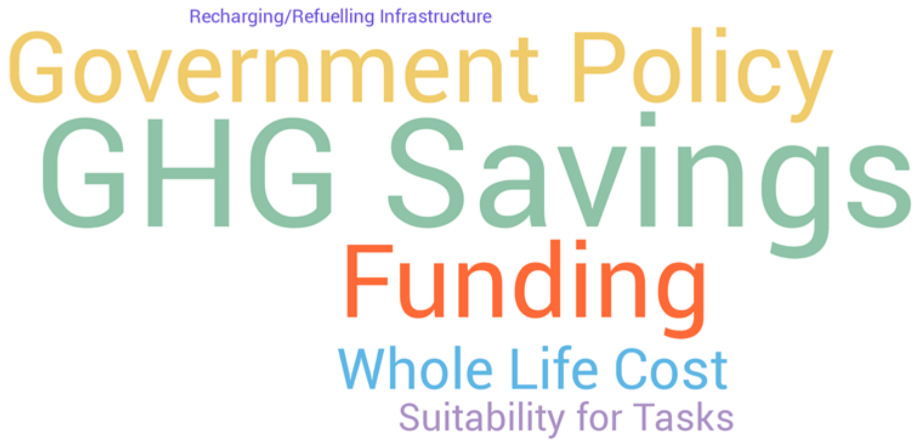


Figure 4.12 Representation of the public sector weighted criteria

The relevant **Governmental Policy and Commitment** appear as one of the most critical factors for the public sector, which must coordinate its planning and operation based on those. It appears to be an important factor for the rail sector as well. In this sector, since it is only now developing its low carbon roadmap, the governmental commitment would be of great value. Rail freight representatives stated that they need and expect this governmental commitment to help them move forward. In the shipping freight that typically operates internationally, the governmental policy and commitment do not have a place in their decision making. It could be roughly stated that the charter-party requirements act as this guiding "authority" for the shipping sector.

Figure 4.13 Representation of the maritime freight sector weighted criteria

For the rail sector, **suitability for tasks** appears to be the equivalent of the **payload** for the road sector, with both highly ranked in their sectors. For the road freight, if the vehicle's payload is not satisfactory, it is almost not viable for the operators to procure low carbon vehicles. While the same happens in rail freight with the suitability for tasks. Suitability for tasks will always be paramount for the sector; no amount of cheapness, government commitment or reliability considerations will take precedence over the need for suitability for the task.

The **recharging/refuelling infrastructure** appears to be weighted relatively low in most sectors, apart from the road freight sector. The importance of the recharging or refuelling infrastructure appears slightly higher in the road freight probably because it is the only sector that faces it as a current issue.

The **range** is one factor that does not appear in the public sector priorities due to their limited geographical coverage and operations scope. The range is the lowest valued criterion for the other sectors, with even lower scores than the relevant infrastructure's existence. This fact indicates that even though the range is active consideration for freight operators, the other criteria, such as WLC, appear highly critical for all of them.

Interestingly, the **GHG savings** criterion was the top criterion only for the public sector—the road, rail and shipping sectors value this as a future goal and achievement. Still, the cost or efficiency of the relevant technology is always prioritised.

4.3 Alignment between Focus Groups and AHP

Whilst the top factors for each group remained similar across the two exercises, some variations in the order of the decision-making criteria are apparent. Although in the focus groups' the participants have been asked for the top five criteria, in the AHP exercise the top six of them were selected for the pairwise comparisons. The following sections compare how the operators' assessment of their priorities varied between the two exercises and considers why this may have occurred.

4.3.1 Road Freight

In **Table 4.15**, the variation between the priorities derived from the road freight sector focus group ranking and the priorities as they were finally weighted using the AHP method.

Table 4.15 Variation in road freight operators' top decision-making criteria

Rank	Focus Group Ranking	AHP Ranking	
1	Whole Life Cost	Reliability	← 3
2	Range	Whole Life Cost	← 1
3	Payload	Payload	=
4	Reliability	Recharging/Refuelling Infrastructure	←1
5	Recharging/Refuelling Infrastructure	Driver Comfort/Facilities	*
6		Vehicle Range	←4

From the table, we can see that while the top decision criteria remain the same, the criteria' ranking has changed notably with the addition of driver comfort/facilities. The *driver comfort/facilities* criterion was ranked sixth in the focus group. It was considered again at the AHP to investigate its influence on the decision-making procedure further.

The significant variation between the highest-ranked criteria derives from two sub-groups between the road haulage respondents, one representing medium-sized operators and one representing large firms. WLC is evaluated as to their highest priority in the first group when thinking about procuring low carbon vehicles or technologies. Whereas reliability is ranked as the most important criterion for the second group. For those, a possible higher upfront or operating cost is not necessarily a barrier if its reliability and payload are sufficient. The latter better explains why reliability climbed higher in the AHP ranking than the focus group one.

4.3.2 Public Sector

The variation between the priorities derived from the public sector focus group ranking and the priorities as they were finally weighted using the AHP method is presented in **Table 4.16**.

Table 4.16 Variation in the public sector's top decision-making criteria

Rank	Focus Group Ranking	AHP Ranking	
1	Recharging/Refuelling Infrastructure	GHG Savings	← 4
2	Whole Life Cost	Funding	← 1
3	Funding	Government Policy	*
4	Suitability	Whole Life Cost	← 2
5	Emissions	Suitability	← 1
6		Recharging/Refuelling Infrastructure	← 5

Interestingly, the ranking of decision-making criteria changed more significantly following the AHP analysis, with emissions dropping from the top 5 and the addition of GHG savings. This is somewhat reflective of discussions held during the focus group. Participants noted that the sector's priorities had moved away from local emissions and air quality toward decarbonisation and greenhouse gas emissions in the past five years.

As discussed with the focus group participants, instead of emissions, it was decided to use GHG savings as a criterion in the AHP, in alignment with the specific focus of this research on the decarbonisation of their fleets. Although not highly ranked in the focus group, this criterion appeared to have the most critical weight in the public sector's decision making. The public sector is the only four sectors that ranked this criterion as important. The operators' nature could explain this: given that these operators do not act towards profit, their primary consideration when procuring low carbon assets is whether they present sufficient GHG savings more than if they are economically viable or efficient.

Government policy was another new addition to the criteria, jumping to the third-most important criterion for consideration. Although this criterion was ranked sixth in the focus group proceedings, it was decided to include it in the public sector AHP model. Indeed, the representatives of the local authorities have ranked it as the third most important in their decision-making procedure, acknowledging their alignment and dependency on the relevant policy.

4.3.3 *Rail Freight*

The variation between the priorities derived from the rail freight focus group along with the priorities as they were weighted using the AHP method is presented in **Table 4.17**.

Table 4.17 Variation in rail freight operators' top decision-making criteria

Rank	Focus Group Ranking	AHP Ranking	
1	Whole Life Cost	Whole Life Cost	=
2	Government Policy	Suitability	*
3	Recharging/Refuelling Infrastructure	Reliability	*
4	Range	Government Policy/ Commitment	← 2
5	Compatibility with network	Recharging/Refuelling Infrastructure	← 2
6		Range	← 2

Suitability and *Reliability* entered the top 5 priorities for the rail freight sector following the AHP analysis, with the loss of *Compatibility with network* from the top rankings. The deeper insights gathered during the AHP exercise have allowed for greater consideration of what compatibility entails, thus resulting in the inclusion of suitability and reliability as subdivisions of one concept. While interviewing the respondents for the AHP method and discussing the criteria as derived from the focus group, it was indicated that *Compatibility with the network* refers mainly to the geometrical characteristics, which cannot be binary compared, as their compatibility is mandatory to proceed. Instead, it was decided that *Suitability for tasks* could better include limitations that might occur when purchasing a low carbon locomotive.

Reliability ranked sixth in the rail focus group, and therefore it was included in the AHP model. Moreover, given that reliability of the asset feeds into its capability to perform tasks, it is understood that these factors are intertwined.

4.3.4 *Shipping freight*

The variation between the priorities derived from the shipping freight sector focus group ranking and the priorities as they were finally weighted using the AHP method is presented in **Table 4.18**.

Changes to the maritime freight operators' top priorities showed the least variance between the focus group and the AHP ranking exercise compared with the other sectors.

Table 4.18 Variation in shipping freight operators' top decision-making criteria

Rank	Focus Group Ranking	AHP Ranking	
1	Whole Life Cost	Subsidies/incentives	← 2
2	Charter party requirements	Charter party requirements	=
3	Subsidies/incentives	Efficiency	← 1
4	Efficiency	Whole Life Cost	← 3
5	Range	Range	=
6	Infrastructure	Infrastructure	=

As mentioned in the analysis (section 4.2.1.3), given the different backgrounds of the shipping freight operators, it was decided to follow a slightly different approach than in the other sectors and consider them as two different respondents. So, as ranked at the focus group, their priorities were kept and transferred in the AHP model, which does not present significant variation.

The main difference in the ranking refers to the WLC, which is differently interpreted by the two operator models. For the large-scale worldwide model, the whole life cost's difference appears not great and is aimed to be covered by the subsidy. Whereas for the European operator, the contracts with the charter parties define the influence of WLC in their operation.

4.4 Key findings

Whole life cost (WLC) was ranked highly by each sector and needed to justify vehicle fleets investments. This was considered easier for road vehicles as many low carbon options are commercially available; however, uncertainty about depreciation rates is a cause for concern for operators with low-profit margins (e.g. 2%-3%). Currently, the cost of LNG is subsidised, making it a viable alternative to diesel for long-haul road freight operators. Electricity is relatively cheap, making electric vehicles a viable proposition for small freight vehicles (e.g. vans), despite higher purchase costs. Calculating WLC for the rail sector was considered impossible at present due to the immaturity of the market. It is anticipated that any modifications to reduce carbon would have significant associated costs as the rail infrastructure itself needs to be updated alongside any new asset.

Similarly, in the maritime group, the WLC of low carbon ships is not yet fully understood. While some alternative fuels are under consideration, such as ammonia and LNG (Liquified Natural Gas), the cost of these fuels is significantly higher than the diesel or heavy fuel oil alternatives currently in use. Therefore, WLC may be a barrier to the adoption of low carbon ships in the maritime freight sector.

The current lack of recharging/refuelling infrastructure in some places (e.g. more remote parts of the UK) and uncertainty about future provision were considered barriers to adopting low carbon assets at this stage. There appears to be a paradox where operators will not procure LNG vehicles until the infrastructure is in place. However, fuel suppliers will not install infrastructure until there is proven demand for the supply. Where infrastructure is widespread, low carbon vehicles are becoming more commonplace. The local authority participants felt they have a responsibility to aid in deploying infrastructure to support the uptake of low carbon vehicles across all road transport. There was preference across the group for an infrastructure model accessible to all, such as a forecourt design for EV charging hubs instead of private charging facilities. This would enable wider uptake of electric vehicles both for private vehicle ownership and freight.

Local authorities are investing in the installation of their own refuelling infrastructure to support hydrogen uptake in public sector fleets, . For the rail sector, any adoption of low carbon rail assets relies on the infrastructure first being in place. Until there is certainty on what infrastructure will be deployed, the operators cannot make purchase decisions. However, it is integral to the operator’s choices in the long term. Infrastructure requirements for the maritime freight sector are complicated by the industry’s international nature, meaning any vessel has to be compatible with ports around the world. As low carbon vessels are still in the early development phase, no solution to this barrier has yet been identified. However, an added complexity is the variance in requirements across different types of freight cargo.

Vehicle range and payload were identified as key factors for the road, rail, and maritime freight sectors. With greater range, there is reduced time required for refuelling or recharging. Therefore, less anxiety is associated with lack of infrastructure. Similarly, the vehicle’s payload affects the efficiency of the entire operation. Long-haul road freight operators often double shift vehicles, meaning that any downtime for refuelling reduces operational efficiency. For this reason, electric vehicles were considered unsuitable, even if payload capacity was increased. It was recognised that the range capacity of low carbon vehicles has improved over the past five years, although suitable options may be limited. The range and weight requirements for rail freight are considerable and, at present, can only be met by diesel trains. Infrastructure would need to be upgraded to support heavy axle loads to allow heavier freight trains access across the whole rail network. The range is an important requirement for the maritime sector. They need to transport goods long distances without the opportunity to refuel. Given the technology's immaturity, it is not clear which alternative fuel will offer the range and payload capacity required. Therefore it is not known if this will be a barrier to uptake.

The maritime freight operators identified subsidies or incentives as being necessary due to the current cost difference between alternative fuels and currently used fuels. The road freight operators stated that subsidies or incentives would increase the uptake of low carbon vehicles but did not consider this a key driver. The rail sector is at an early stage in the development of low carbon rail options (other than overhead electrification). So the consideration for incentivising uptake may not be as applicable here. However, it was noted that what little funding the sector has for trials has come from private investors rather than the government. The public sector noted that government funding would be required to support infrastructure rollout and the uptake of low carbon vehicles.

Reliability was identified as the most important factor for the road freight group. They considered that low carbon freight vehicles are currently less reliable than their diesel comparators. However, they suggested that reliability was improving over time. The fact that many garages are not equipped to service alternatively fuelled vehicles was also a concern.

Efficiency was identified as a top priority for the maritime freight sector. This was considered to mean the ability of the vessel to move freight at a speed that meets the time restrictions of the charter party and has the payload capacity to move large amounts of freight in a single journey. Its absence as a top criterion in the other sectors could be because the fuel efficiency is a factor that feeds into the whole life cost calculation rather than as a stand-alone criterion.

The vehicle's suitability or capability was a priority for the public sector and rail groups and considered challenging to procure. The public sector group tend to operate mixed vehicle fleets, ranging from small vans to large refuse collection vehicles and with different needs depending on the area geography, infrastructure, and congestion; therefore, there is no simple vehicle solution across different local authority areas or within one local authority fleet. The public sector participants did not feel equipped to understand which low carbon technology is suitable for which task with multiple factors under consideration. Greater understanding of the advantages and disadvantages of adopting low carbon technologies is needed to aid an informed choice. The rail freight group noted that no viable solution had emerged yet with diesel's capability. Electric powertrains are the most promising alternative, but the weight of batteries reduces payload. Hydrogen may be a future fuel option for rail, but there is no route where this can be deployed yet. Hence, it is too early to understand the capability.

The public sector group gave vehicle emissions as a key driver. Many local authorities have ambitious targets to improve air quality, with measures including low emission or clean air zones. To set a good example, they also aim to decarbonise and lower their own vehicles and operations emissions. The private sector is not under the same pressure to decarbonise their operations, and purchase decisions are motivated more by making a profit in their businesses by operating efficiently.

5 Conclusions

5.1 Overview

This study has consulted 24 participants with freight transport investment responsibilities in the road, rail, maritime and public sectors. Such consultation is essential and necessary to understand practitioners' viewpoints, their key drivers for investment , and barriers to decarbonising fleets. The participants ranged from three, in the maritime sector, to nine in the road sector, with six each from the rail and public sectors. While the findings would be bolstered with larger groups, we are confident they are of value and meaningful due to the high degrees of consistency found in individual responses and the consensus between participants.

The key drivers for decarbonising UK freight were seen to vary to some extent between sectors; however, whole life cost was deemed very important across all the sectors. This indicates that to decarbonise freight, the UK Government should implement policies that support the delivery of economies of scale that will translate to cost reductions until cleaner technologies reach cost parity with incumbent technologies. Different governments worldwide have succeeded with policies promoting direct subsidies, grants, research and innovation credits or green fleets procurement schemes that can cover the price differential between newer decarbonised freight solutions and the conventional ones . Mandates forcing fleets to decarbonise is another approach that has been used with success in other sectors and countries. This includes GHG emissions standards or phasing out fossil fuels by a particular date. This is feasible; however, challenging for those organisations operating cross-borders. Unless the same rules bind international freight organisations, they can gain a competitive advantage that, in a sector with such tight profit margins, could threaten the survival of local businesses.

While WLC is the most important driver, it is not the only one. Operational factors clearly discriminate certain options. The role of international standards and regulations also play an important role as it is necessary to deploy global networks / corridors of alternative recharging / refuelling infrastructure to cater the needs of long-distance freight.

The policy landscape is a decisive source of uncertainty that deters the uptake of decarbonised solutions. As the life of vehicles tend to last between 7 years in the case of HGVs, to decades in the case of ships or rolling stock, procuring fleets fitted with a fuel powertrain / energy pathway that does not become the market standard can lead to stranded assets and irreversible consequences that could jeopardise the very existence of these organisations.

The transport sector needs to move very swiftly to meet UK national decarbonisation targets. Time horizons are also critical, as also operational needs and the policy context. According to broader technological roadmaps, the right mix of solutions will vary within and between local authorities and according to broader technological roadmaps. There will likely be a combination of net-zero emissions freight fleets where certain powertrains will be better suited for particular duty cycles, payloads and operational constraints. Technology change alone is not enough, and behavioural changes are likely to impact significantly. Transport strategy must embed decarbonisation at its core, rather than seeing carbon as an add-on. Delivering a zero-carbon future for transport will require collaboration between citizens, industry, and government. To achieve the economies of scale needed to improve cost-efficiency and make this possible, policy support is required from the central government to enable local authorities to decarbonise their freight fleets.

5.2 Further Research

Further work is required to understand the relevance of business models on the investment of decarbonised freight. Type of ownership also plays a role, and while the total cost of ownership is a top priority, sensitivity analysis would provide further insights and drive the decarbonisation agenda forward by sharing the benefits (e.g. owner / lessors, charter agreements, etc.).

Some potential differences may exist when comparing well-established freight organisations with start-ups. Some start-ups counting on financial muscle may be keener on investing in innovative solutions. At the same time, more mature organisations compete fiercely to deliver any profitability.

This study focused on road hauliers, mainly running regional or long-distance operations. City logistics operators have more technologies available (e.g. battery electrification is feasible for most), while long-haul options are much more limited; electric road systems, battery electric and hydrogen fuel cell HGVs will be demonstrated in the UK market in the coming years. Further qualitative research will be required to understand how these alternatives influence freight operators' decision-making, based on the outcomes of demonstrations (e.g. total costs of ownership, reliability issues of vehicles and recharging/refuelling infrastructure, safety concerns, policy landscape, etc.).

We believe that some work is required to change the decarbonisation narrative, as there are decarbonisation pathways that still produce air quality emissions. It would also be insighful exploring bottom-up approaches to drive decarbonisation within logistics, from the perspective of the consumers. This is something that could be investigated in citizen assemblies.

Macro-economic models and program evaluation of publicly funded demonstrators could reveal the impact that new decarbonised freight technologies have on the economy, society, and environment, and use this to inform research priorities and innovation policy. We also identified a knowledge gap that causes a lack in confidence on what really works. This could be filled with the independent monitoring and evaluation of future trials.

It can be argued that considering the competing uses of low carbon energy pathways, further research is necessary to produce whole energy system modelling results to allocate different alternatives to the optimal end use across different economic sectors. This would require more granular datasets of the different vehicles modes and categories. The lack of harmonised international standards (e.g. green hydrogen certificates, renewable certificates) and taxation regimes need to be aligned to identify unfair competitive advantages for freight businesses located in countries with less stringent decarbonisation targets, standards and policies.

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Appendix A Focus group topic guide

Introduction and consent

Thank you for agreeing to take part in this study into decarbonisation technologies for freight.

The study specifically focuses on the main factors that steer organisations to choose to invest in cleaner freight fleets and their infrastructure. We would also like to explore how the factors that drive your investment decisions have changed over time and might change in the future. As well as this focus group, we will be holding focus groups with representatives of [rail/road/shipping/public authority] organisations.

The study will aim to reveal the barriers to low carbon freight technology uptake, as well as solutions to increase the uptake of these technologies, particularly in relation to the current climate emergency, and energy and transport policies.

We, TRL, are undertaking this research as part of a multidisciplinary research project called Decarbonising UK Freight Transport, which is funded by the UK Engineering and Physical Sciences Research Council.

As mentioned in the Advanced Communication document, we will take notes during this focus group and, if you agree, we will record it. The recording is to act as a back-up and a resource for us to review notes after the group. It will be deleted after the report is completed. We will mainly be reporting overall themes that emerge from these focus groups, although some quotations may be used to illustrate the main points. All quotations will be anonymised so that they are not able to be personally attributed to you, other than your stakeholder group. Do you have any questions about this or anything else?

Our main aim today is to identify the key factors behind organisations' low-carbon freight investment decisions.

The group will take no longer than two hours. If we are running to schedule, we will have a 5-minute comfort break about halfway through. But please feel free to pause your camera and take a break if you need to at any point

We may need to move discussions along to ensure we cover all our questions.

> *[Consent was obtained prior to the focus groups, but if any participants had not completed their consent form, they were asked verbally]. So just to run through your agreement on a few points. Do you agree that:*
>
> *1. I have read and understood the information provided in the Advanced Communication document and have had the opportunity to ask questions*

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason

3. I agree to the interview being recorded

4. I understand that anonymised quotes from this focus group might be used in the final report

5. I agree to take part in the study

If you are happy to proceed, I will start recording

-START RECORDING-

Warm-up activity

So, as a way of introductions, can you each tell the group your name and your role in your organisation. Also, the size of your freight fleet and whether you have already invested in any low carbon freight technology.

Exploring decision criteria

In this first section of the focus group, we are going to discuss what factors most influence your decisions about buying and investing in freight fleets. We'll start by generating a list of these factors, before going into why they are a factor, and then discussing their relative importance in the decision-making process.

[List in Mentimeter] What criteria does your organisation consider when investing in freight vehicles? Please limit your list to a maximum of 7 factors.

- *Prompts: [If not mentioned enquire about the following]*

General procurement factors	Exclusive Criteria in the procurement of low carbon technologies
Total cost of ownership Power Accessibility to low emission zones Taxation (congestion charge) Taxation (of fuels) Training needs for drivers CO2 emission standards Air quality pollution Noise pollution Alignment with public policy Budgets	Range of vehicles, vessels, locomotives Impact of low carbon technology on vehicle payload Recharging time batteries Availability of recharging or alternative refuelling infrastructure Reliability of the technology/systems Safety concerns (NIMBY) Subsidies / grants Priority loading/unloading bays (traffic regulations) Access to priority lanes (traffic regulations) Maturity of technology / Technology readiness level

General procurement factors	Exclusive Criteria in the procurement of low carbon technologies
Others	Maturity of the supply chain (spare parts) Skills needed to maintain fleet Brand awareness / Reputational benefits Others

Why are they a factor?

Let's take each criterion in turn and think about why they are a factor and if and how they relate to the procurement of low carbon freight vehicles specifically.

Why is <criterion> a factor? Why is it important?

> *Prompts: For example, maximising profit/safety/efficiency, company's reputation, need to meet regulations (e.g. emission standards) …*

Do you have any experience/examples which demonstrate why <criterion> is important?

Discussion of importance

We would now like to consider which are the top three five most important factors from the list we have produced, and why. Then decide on your bottom three – i.e. your least important factors. Please select the TOP FIVE factors that you would consider when purchasing freight vehicles in general. Please rank these in order (most important factor first) for YOUR ORGANISATION using Mentimeter, then press submit.

Here is our top 5 list overall for general freight decisions. Would anyone say that the top 5 list for their organisation is different to this list? What would be more/less important to your organisation? Why is <criterion> important to your organisation but not yours?

> *Prompts: Organisation size? Vehicle types (HGVs/LGVs)?*

Here is our top 5 list overall for low carbon freight decisions. Would anyone say that the top 5 list for their organisation is different to this list? What would be more/less important to your organisation? Why is <criterion> important to your organisation but not yours?

> *Prompts: Organisation size? Vehicle types (HGVs/LGVs)?*

If total cost of ownership is the top factor – why do you invest in low carbon freight?

Exploring criteria over time

We've managed to generate a list of criteria that you feel are important when making decisions about investing in decarbonising freight. We've also managed to get an idea of how important each of these factors are. Now I would like us to start exploring how these factors have changed over time, and how they are expected to change in the future.

What has changed over the last five years?

Think back to five years ago. Was there any difference in how important any of the criteria were then compared to now?

Prompts: Do you feel there is greater availability of low-carbon alternatives (e.g. EVs, biodiesel) within your industry? Where do you feel <criterion> was five years ago? And where do you feel it is now?

Do you have any experience/examples which demonstrate how things have changed?

[Try to create a two-point timeline of changes on each factor that has been raised. "Five years ago, <criterion> was… Now it is…".]

What will change over the next five years?

Looking forward in time, how do you think things will change over the next five years in relation to these factors?

Prompts: Are you aware of any ongoing developments in this area that may change things over time? Where do you feel <criterion> will be in five years compared to now?

Will there be any factors that might become important in five years that are not important now and haven't been mentioned?

[Try to build on the timeline started in 2.1 to create a three-point timeline of changes on each factor – Five years ago > now > five years in future.]

Discussion of barriers and how to overcome them

In the next part of the focus group, we are going to explore the various barriers that you feel are associated which each of the factors we have raised. Following that, we will conclude this group discussion by exploring possible solutions to overcome these barriers. We can take each factor in turn, to identify and discuss barriers; then we can take each barrier in turn and think about what might help remove or reduce their impact.

What barriers are associated with each factor?

What barriers do you feel exist to the uptake of low-carbon fleets for organisations such as yours (e.g. batteries, hydrogen fuel cells, retrofitting)?

Prompts: Are there infrastructure limitations?, What does the regulatory environment look like?, Is there a lack of financial opportunities or incentive schemes?, What about educating people on the need for decarbonisation? trade-offs between clients wishing lower carbon fleets and wiling-ness to pay higher rates?

Looking at the barriers we have listed, what do you think can be done to overcome them to improve the uptake of low-carbon technology (e.g. EVs, biodiesel)?

Prompts: What can be done to make <criterion> less of an issue? Are there regulations or financial/incentive schemes you could imagine that would help?

[Try to gather a suggestion for each identified factor. May be possible to create a diagram of solutions mapped to each barrier that is associated with each decision criteria].

What barriers do you think may exist for these factors in the future?

Prompts: For example, is there uncertainty over future energy prices? Will infrastructure be able to support the increasing demand for freight? How phasing out diesel will impact your operations and bottom line.?

Aim is to gather a list of identified barriers mapped to the identified decision criteria. List for current barriers and list for future barriers.

Looking at the barriers we have listed, what do you think can be done to overcome them to improve the uptake of low-carbon technology (e.g. EVs, biodiesel)?

Prompts: What can be done to make <criterion> less of an issue? Are there regulations or financial/incentive schemes you could imagine that would help?

[Try to gather a suggestion for each identified factor. May be possible to create a diagram of solutions mapped to each barrier that is associated with each decision criteria].

Decarbonising UK Freight Transport: Understanding Freight Decarbonisation Investment Decisions

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ISSN

ISBN

PPR2002