Freight Electric Vehicles in Urban Europe

D3.3 Systemic Transport and Environmental Impact of EFVs in Logistics

Report

Work package: WP3 Analysis

Date of delivery: 12 September 2017

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Version: v2.0

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 321622

Document control

Acronym	FREVUE
Project no.	321622
Project title	Freight Electric Vehicles in Urban Europe
Work Package no.	WP3
Work Package title	Analysis
Deliverable no.	D3.3
Deliverable title	Systemic Transport and Environmental Impact of EFVs in Logistics Report
Dissemination level	Public
Issue date	12/09/2017

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Responsible organisations	Imperial College London
WP Leader	Imperial College London
EC Project Officer	Antonio Scala

Amendment history

Version	Date	Author	Description/Comments
v0.1	23/03/16	Yanjie Dong, John Polak	Draft outline
v0.2	24/03/16	Tanja Dalle-Muenchmeyer	Comments on draft outline
v0.3	31/03/16	Yanjie Dong, John Polak	Final draft outline
v0.4	11/04/17	Yanjie Dong, John Polak	First full draft
v0.5	13/04/17	Tanja Dalle-Muenchmeyer	Comments on first full draft
v1.0	20/04/17	Yanjie Dong, John Polak	New version sent to the coordinator, Tanja Dalle-Muenchmeyer.
v1.0	20/04/17	Tanja Dalle-Muenchmeyer	v1.0 for submission
v2.0	05/09/17	Yanjie Dong, John Polak	v2.0 Final version
v2.0	12/09/17	Tanja Dalle-Muenchmeyer	v2.0 for submission

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Glossary

AAD	Annual Average Day
AADT	Annual Average Daily Traffic
CAF	Central Analysis Framework
CO_2	Carbon Dioxide
COPERT	Computer programme to calculate emissions from road transport
DoW	Description of Work
EC	European Commission
EFV	Electric Freight Vehicle
GHG	Greenhouse Gases Emissions
HGV	Heavy Goods Vehicle
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
LGV	Light Goods Vehicle
LoHAM	London Highway Assignment Model
NO_2	Nitrogen dioxide
NO_x	Nitric oxide & nitrogen dioxide
PM	Particulate Matter
SoC	State of Charge
TAG	Transport Appraisal Guidance
UCC	Urban Consolidation Centre
VMA	Amsterdam Traffic Model

Executive summary

Road freight transport delivers many benefits to our society. It allows for the movement of goods and services, supports economic growth and provides employment opportunities. However, despite these benefits and significant progress of technological and efficiency improvements over the years, road freight transport is a major contributor to greenhouse gases (GHGs) and air pollution. These negative impacts result in a deterioration of both human health and the environment, and thereby cause significant economic costs to our society.

To respond to these challenges, the FREVUE project has deployed 80 fully electric freight vehicles, from light vehicles under 3.5 tonnes to 18 tonne trucks for various logistics operations across eight European cities. The project aims to prove that the current generation of electric vans and trucks can offer a viable alternative to diesel vehicles - particularly when combined with state of the art urban logistics applications, innovative logistics management software, and well-designed local policy.

This deliverable aims to measure, analyse and quantify the environmental impacts of the demonstrators from running electric freight vehicles (EFVs) instead of using conventional internal combustion engine vehicles (ICEVs). The analysis is carried out at three levels: the first level looks at direct environmental impact quantification from FREVUE demonstration activities. The second level examines potential environmental impacts at different EFV penetration levels to address the issue of small scale deployment of EFVs. The third level analysis aims at monetising the wider systemic and environmental benefits. This helps better understand the overall impacts of current and future implementation of EFVs and may also be used for setting out new policies to encourage future uptake of EFVs.

The first level analysis presents the results by comparing EFV with different ICEV technologies (or emission standards). Assuming all vehicles have a load factor of 50% and no load reduction as a result of electrification of the fleet, it is shown that over the whole period of project demonstration activities, the FREVUE demonstrators bring NO_x savings of 2147.5 kg and total PM_{10} savings of 72.2 kg if replaced ICEVs are assumed to be Euro 3/III vehicles. This is equivalent to total road transport NO_x emissions in the City of London for three days in 2013 and total road transport PM_{10} emissions in the City of London for two days in 2013. If the baseline ICEVs are newer Euro 6/VI vehicles, the overall benefits from FREVUE demonstrations amount to NO_x savings of 628.6 kg and PM_{10} savings of 1.4kg. There is significant reduction of benefits when comparing Euro 6/VI to Euro 3/III results due to better performances and improvements of emission control technologies used in the newer vehicles. In the FREVUE project, the majority of replaced ICEVs were either Euro 3/III or Euro 4/IV. Therefore, the overall direct benefits are significant.

GHG emissions are not directly related to the emission standards. Our analysis shows that the local GHG savings are between 385 and 400 tonnes CO_2e, and the total GHG environmental loads, using well-to-wheel analysis, are between 176 and 190 tonnes CO_2e. This represents an overall saving of 45 percent and is equivalent to total road transport GHG emissions in the City of London for about one day in 2013. However, significant variations can be observed between different operators and cities. For example, in Oslo where smaller light goods vehicles were deployed and the carbon intensity of the local electricity generation is very low, they have achieved a GHG saving of over 90%. In other cities where carbon intensity of the electricity grid is high, net GHG savings can be less than 10% under certain operational conditions. As the power sector is gradually decarbonised, the total GHG emission benefits would improve by using EFVs.

The second level analysis looks at potential environmental impacts at different EFV market penetration by using traffic models. Two models have been obtained from FREVUE demonstration cities, including the LoHAM model from London and the VMA model from Amsterdam. The analysis on the spatial distribution of freight traffic from these models show that majority of the heavy goods vehicle flows (with gross vehicle weights of 3.5t or above) are concentrated around motorways or major roads. However, light goods vehicles (LGVs) penetrate deeply into all types of roads. Therefore, more health benefits can be achieved by electrifying light goods vehicle groups due to their presence in residential areas and city centres.

Results from the level two analysis show that if in the year 2021, 10% (low penetration level) of all freight vehicles[1] within the London M25 area were to be electric, this would result in maximum yearly CO_2 savings of 2.8 million tonnes, NO_x savings of 402 tonnes and exhaust PM_{10} savings of 3.8 tonnes. The benefits for medium (50%) and high (100%) penetration levels are much higher. In 2031, due to a wider deployment of Euro VI/6 vehicles with better emission control technologies, the NO_x and PM_{10} reductions are smaller compared to 2021 results under similar penetration levels, with 2489 tonnes and 16.8 tonnes savings per year respectively within the M25 area for the high penetration scenario. The CO_2 maximum achievable emission savings, however, increase to 2.9 million tonnes per year due to higher vehicle mileages which are predicted by traffic models. Analysis for Amsterdam also shows significant savings for the forecast years 2020 and 2030.

Based on the results from the level two analysis, the third level analysis estimates the monetary values from air quality improvements and GHG reductions. Only London is analysed due to the availability of key parameters. It is calculated that at the low penetration level for the year 2021 (10% uptake levels), using the central value scenario (the most likely scenario), the total benefit discounted to 2017 price from air quality improvement based on damage cost reduction is 0.3 billion pounds, and total benefit from GHG savings is 13.5 million pounds at the 2017 price. In year 2031, the benefits of air quality improvement for a high penetration level are expected to reach 1.8 billion pounds, and the benefit of GHG savings is valued at 184 million pounds at the 2017 price.

The overall conclusion of this report is that the electric vehicles deployed as a part of the FREVUE project have produced good environmental benefits, even at the average carbon intensity of electricity generation during the project. A substantial amount of existing freight traffic can be electrified based on the length of the journeys and if a higher EFV penetration is achieved, a substantial level of air pollutant reduction and GHG savings are expected, along with significant economic benefits. The amount of economic benefits from wider environmental benefits should also be considered during the process of new policy evaluations.

[1] Based on the ICEV fleet composition forecast provided by Defra

1 Introduction

1.1 Background and overview of FREVUE

As part of the FREVUE project, eight of Europe's largest cities, including six capitals, demonstrate that electric vehicles operating "last mile" freight movements in urban centres can offer significant and achievable decarbonisation of the European transport system.

The public-private partnership of FREVUE, which brings together 17 industry partners, nine public sector bodies and six research and networking organisations, jointly deploys demonstrators in Amsterdam, Lisbon, London, Madrid, Milan, Oslo, Rotterdam and Stockholm. The demonstrators have been designed to ensure FREVUE covers the breadth of urban freight applications that are common across Europe, including a wide range of:

- Goods deliveries (including food, waste, pharmaceuticals, packages and construction goods)
- Novel logistics systems and associated ICT (with a focus on consolidation centres which minimise trips in urban centres)
- Vehicle types (from small car-derived vans to large 18 tonne goods vehicles)
- Climates (from Northern to Southern Europe)
- Diverse political and regulatory settings that exist within Europe

By exposing over 80 electric vehicles to the day to day rigours of the urban logistics environment, the project aims to prove that the current generation of electric vans and trucks can offer a viable alternative to diesel vehicles - particularly when combined with state of the art urban logistics applications, innovative logistics management software, and with well-designed local policy.

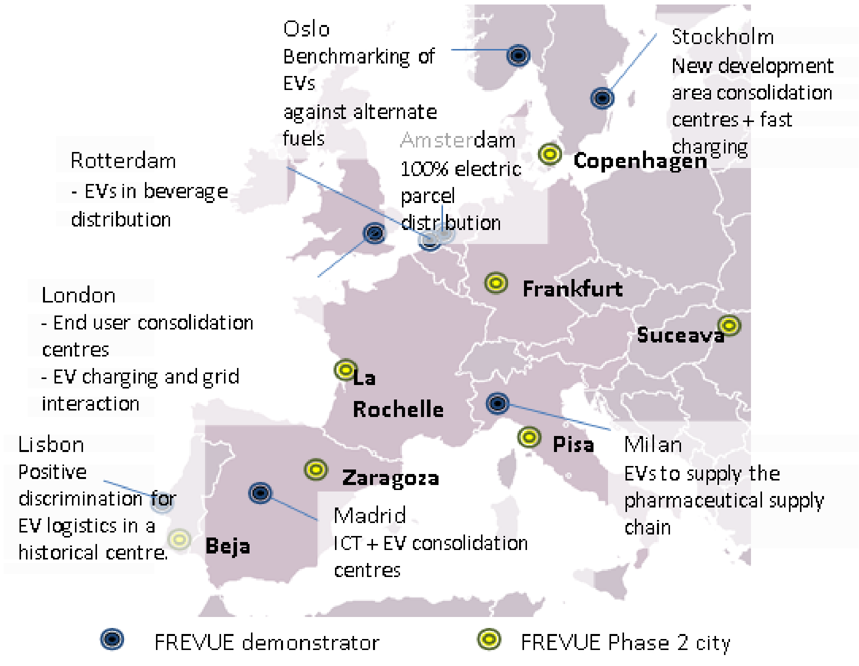


Figure 1: FREVUE demonstrator activities

The project demonstrates solutions to the barriers currently inhibiting uptake of EVs in the sector. Novel leasing and procurement models are explored to help mitigate the high capital cost penalty for EV purchase. The impact of a wide range of local policies on the overall ownership case for EVs in logistics applications is also tested.

The project includes leading European research institutions with expertise in transport policy, logistics and electric vehicle technologies. These institutions have designed and implemented a data capture protocol and subsequent assessment framework for the project. This ensures that the project creates a valuable European evidence base on the role of EVs in urban logistics. Partners will produce clear guidelines and recommendations targeted towards the key focus groups of this project: Freight operators and fleet managers, public authorities at the local and regional level, energy network operators, ICT and service providers, and vehicle manufacturers.

These guidelines and recommendations will feed into a targeted dissemination campaign to ensure that the results of the study reach an audience that will be able to act on the findings of the study and hence increase take-up of EVs in urban logistics. To complement this, FREVUE also created a network of "Phase 2" cities to directly share the lessons learned from the demonstrators. These cities are expected to be the first to expand the successful concepts developed by FREVUE.

1.2 Work package overview

The FREVUE project is broken down into five work packages, which are described below:

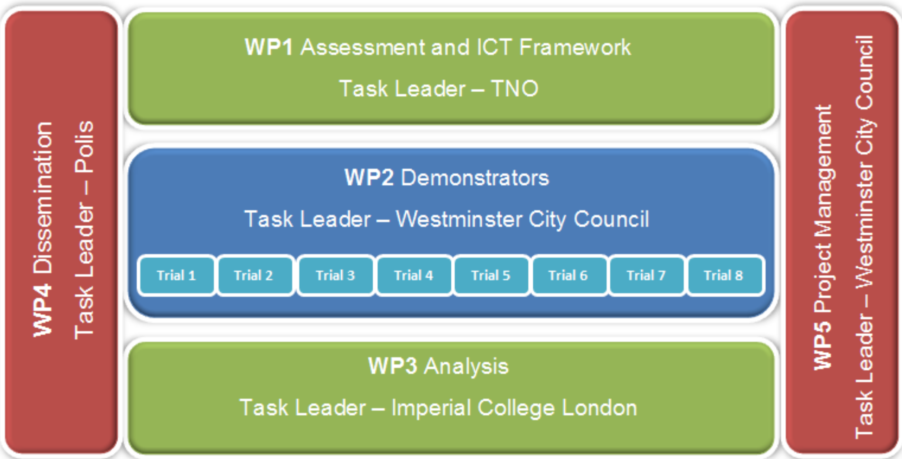


Figure 2: FREVUE work packages

WP1 – Assessment and ICT Framework: This work package defined the data protocols, data handling procedures and assessment framework for the demonstrators. This ensures that all required data is gathered and correctly communicated during the demonstrator operations. In addition, a review of state-of-the art logistics ensured that lessons from previous projects were taken into consideration during the planning phase for the demonstrators. Due to the dynamic and fast-changing situation around electro-mobility and urban logistics, it was agreed to update this state-of-the-art report in mid-2015 and in February 2017.

WP2 – Demonstrator trials: This package contains all aspects of the delivery of the demonstrators. Each trial has a local project manager responsible for day to day delivery of the project and the implementation of the data collection frameworks agreed in WP1. The trials follow a common structure across the eight trans-national demonstrators.

WP3 – Analysis: Data from the demonstrators is analysed and relevant conclusions for the logistics industry and policymakers are drawn including:

- Technical and economic performance of the demonstrators in FREVUE
- Environmental performance of the demonstrators (with respect to CO_2), and analysis of impacts for wider scale deployment (for air quality, congestion and the electricity grid)
- Social impact of the EV logistics applications and policies (e.g. curfew extension)
- Impact of the range of policies on the economic case for the logistics operators to deploy EVs
- Any safety issues arising during the demonstrators

WP4 – Dissemination: The dissemination activity is the key to the project and will target professionals in the logistics and ICT industries, energy network operators, vehicle manufacturers as well as policy makers with the potential to unlock further EV deployment in logistics. The task also includes direct "officer to officer" dissemination to the Phase 2 cities who have expressed interest in deploying similar programmes in the near future.

WP5 – Project coordination and management: This WP oversees the project overall and ensures efficient reporting to DG Move, that partners in the project are communicating effectively, that the project is progressing on schedule and that issues are identified at an early stage and dealt with promptly.

1.3 Deliverable objective and scope

This deliverable documents the findings from Task 3.3 – systemic transport and environmental impacts of EFVs for logistics in work package 3.

Objective

The objective of this report is to measure, analyse and quantify the systemic impact of the demonstrators on the operation of the transport system and its environmental consequences. To be more specific, it aims at answering the following three questions:

1. What are the direct impacts of EFVs to the transport system and environment for each of the demonstrators?
2. What are the potential traffic and environmental impacts at a higher EFV penetration level?
3. Whether it is possible to, and if so how, quantify these systemic impacts in monetary terms?

Scope

The nature of the impacts that will be taken into account includes impacts from utilizing EFVs in the following areas:

- Impacts on air quality caused by the reduction or elimination of tailpipe emissions
- Impacts on both local CO_2 emission and on total CO_2 environmental load, taking account of the nature of electricity generation
- Impacts on the safety of road users (drivers, pedestrians, cyclists and others) caused by EFV based freight operations as a result of e.g. quieter vehicles and potentially greater vehicle penetration into sensitive residential areas

- Impacts on noise nuisance for residents, workers, and other users caused by quieter vehicle

A special task was set up in WP2 (task 2.4 Safety task force) to ensure safe operation of demonstrators and collection of safety issues. Over the duration of the FREVUE demonstration, no safety related issue has been reported. Hence for the safety related impacts, quantitative analysis cannot be carried out in this deliverable. However, this issue is part of the survey analysis dimensions in task 3.4 Social and Attitudinal impact. Therefore, it is further discussed in the D3.4 report on attitudinal and social impacts of EVs. For other dimensions of impacts, the direct effects associated with the demonstrators themselves will be measured at first where possible. This depends on data availability from each demonstrator and more detailed discussions are available in Chapter 2.

To overcome the issue of small scale deployment of EFVs and to further estimate the impacts under different assumptions regarding the market penetration of EFVs, strategic traffic models are used to selectively generalise the results. These models also take account of the non-linearities of aggregation that are pervasive in transport and logistics networks and of the complex interaction between each dimension (e.g. changes in congestion will affect vehicle energy use and emissions).

Where possible, these systemic impacts are quantified in monetary terms using standard transport appraisal methodologies[2], for example, the valuation of changes in local air pollution and CO_2 emissions.

Most of the data used for this task was provided by the site demonstrators on a monthly basis and, after sense-checking were uploaded to a main database which was maintained on a central system by FREVUE research partner SINTEF.

Target audience

The target audience for this deliverable includes but is not limited to:

1. logistics operators: most of the operators in the FREVUE project stated to take their environmental responsibilities seriously. Outcomes of this deliverable will enable them and other non-FREVUE operators to see what difference they have made or could make to the environment by electrifying their fleets
2. (local) authorities/policy makers: they are the acting group on improving air quality and living environments for citizens. The analysis of these results enables a fuller understanding of the overall impacts of current and future deployments of EFVs. This will help them make a better-informed decision (in addition to the business aspect which is discussed in D3.2) when choosing any policy tools to facilitate the process of electrifying city logistics.

Added value

Freight traffic is an important source of congestion, air pollution and other traffic problems, especially in the cities. However, comparing with passenger traffic, relatively little research has been done in this area. This deliverable aims to tackle this by using traffic models to identify the likely impacts to the environment and transport network for different uptake levels of EFVs. Hence it makes it possible to quantify the difference to air quality that changes to the city logistic sector make.

[2] Department for Transport (United Kingdom), Transport analysis guidance: WebTAG, https://www.gov.uk/guidance/transport-analysis-guidance-webtag

1.4 Structure of this deliverable

This deliverable is structured as follows:

Chapter 2 presents results of direct impact estimations from running EFVs at each of the FREVUE demonstrators. These include air quality impacts based on the "hot" (at the engine's full operational temperature) exhaust emissions as well as local and total CO_2 emissions using well-to-wheel analysis. Like-for-like replacement between the conventional ICE vehicles and electric freight vehicles are assumed and results are presented by comparing emission savings with different vehicle technologies (or emission standards) to generalise the impacts.

Chapter 3 presents the results of potential impacts at different EFV penetration levels, based on the analysis using transport models of London and Amsterdam. A brief introduction is given to the models of the two cities and how the freight demand is modelled. Then the trip length distributions of freight traffic, spatial distribution of freight traffic and future fleet composition forecast are analysed to see what percentage of freight can realistically be electrified. The impact on air quality and GHG emissions are then carried out and results are presented by three scenarios, including low, medium and high uptake of EFVs in the future.

Chapter 4 discusses the methodologies and results from monetisation of the environmental impacts at different EFV market penetration levels identified in Chapter 3. The current approach used in transport scheme appraisals is introduced. Due to the requirements of previous studies on many monetisation factors, London is used as a case study to demonstrate how the monetisation would work and what kind of wider environmental impact it has.

2 Estimation of direct systemic and environmental impacts

2.1 Introduction and assessment methods

This chapter presents direct estimation of systemic and environmental impacts as a result of EFV deployment for each of the FREVUE demonstration cities. The dimension of analysis includes impact assessment on air quality, greenhouse gases (GHG) emissions at both the exhaust level and environmental total level and impacts on noise.

For each of the assessment dimensions, a detailed review of the background information is provided, introducing type and source of the emissions, impacts of the emission, the share of road transport and the role of EFVs in reducing the emissions. This is followed by an introduction to the analysis methods and analysis strategy that are used in this deliverable.

In the second part of this chapter, FREVUE data is presented, including amount and type of data which are available for the environmental impact analysis. The issue around data quality is introduced, along with the data cleaning process implemented on different parameters.

In the last part of this chapter, detailed environmental analysis is carried out for each demonstrator. Results are then aggregated and presented at the city level.

2.1.1 Impacts on air quality

2.1.1.1 Background

Air pollution is a complex problem and an important environmental, social and health issue. It affects people's life and environment in many different aspects, including human health, ecosystems, biodiversity, climate change, the built environment, cultural heritage, and economic impacts.

According to the European Environmental Agency (EEA, 2016b), estimated health impacts due to exposure to $PM_{2.5}$ concentrations in 2013 were responsible for about 436,000 premature deaths originating from long-term exposure in the EU28. The estimated impacts of the exposure to NO_2 and O_3 concentrations in 2013 were around 68,000 and 16,000 premature deaths per year respectively in the EU28. These figures do not show significant changes over the years. Based on a study conducted by WHO (2013), the air pollutants also contribute to health problems in fertility, pregnancy, new-borns and children. The negative impacts on neural development and cognitive capabilities from air pollution can then lead to worse performance at school, lower productivity and quality of life. The overall annual economic cost of health impacts and mortality from air pollution, including estimates for morbidity costs, stood at US$ 1.575 trillion (or EUR 1.48 trillion) in the WHO European region in 2010 (WHO Regional Office for Europe, 2015).

Air pollutants are emitted from anthropogenic and natural sources and they may be either emitted directly (primary pollutants) or formed in the atmosphere (as secondary pollutants). The type of pollutants, their sources and health impacts are summarised in Table 1:

Pollutant	Description and sources	Health and environment effects
Sulphur dioxide (SO_2)	SO_2 is formed by oxidation of sulphur (S), mainly through combustion of fuels containing S. The electricity generation sector is the most important source of SO_2. SO_2 also can contribute to the formation of secondary sulphate particles in the atmosphere.	SO_2 aggravates asthma and can reduce lung function and inflame the respiratory tract. It can cause headache, general discomfort and anxiety. SO_2 contributes to acid deposition, the impacts of which can be significant, causing damage to forests and ecosystems in rivers and lakes.
Nitrogen oxides (NO_X)	NOx is emitted during fuel combustion e.g. from industrial facilities and the road transport sector. NO_x is a group of gases comprising nitrogen monoxide (NO) and nitrogen dioxide (NO_2). NO makes up the majority of NO_x emissions. NOx contributes to the formation of ozone and particulate matter.	NO_2 is associated with adverse effects on health: it can affect the liver, lung, spleen and blood. It can also aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection. As with SO_2, NO_x contributes to acid deposition but also to eutrophication of soil and water.
Particulate matter (PM)	PM is a mixture of aerosol particles (solid and liquid) covering a wide range of sizes and chemical compositions. PM_{10} ($PM_{2.5}$) refers to particles with a diameter of 10 (2.5) micrometres or less. PM is either directly emitted as primary particles or it forms in the atmosphere from emissions of SO_2, NO_x, NH_3 and NMVOCs. PM is emitted from many anthropogenic sources, including both combustion and non-combustion sources. Important natural sources of PM are sea salt and natural re-suspended dust.	PM can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias. It can also affect the central nervous system and the reproductive system, and can cause cancer. One outcome of exposure to PM can be premature death. PM also acts as a greenhouse gas, mainly cooling the earth's climate, although in some cases it can lead to warming. PM in the atmosphere can also alter rainfall patterns, and affect the surface albedo properties of snow (the extent to which the snow reflects light).
Ozone (O_3)	Ground-level (tropospheric) ozone is not directly emitted into the atmosphere. Instead, it forms in the atmosphere from a chain of chemical reactions following emissions of certain precursor gases: NO_x, carbon monoxide (CO) and NMVOCs and methane (CH_4).	Elevated levels of ozone can cause respiratory health problems, including decreased lung function, aggravation of asthma, and other lung diseases. It can also lead to premature mortality. Ozone is also a greenhouse gas contributing to warming of the atmosphere.
Ammonia (NH_3)	The vast majority of NH_3 emissions come from the agricultural sector, in connection with activities such as manure storage, slurry spreading, and the use of synthetic nitrogenous fertilisers. It also contributes to the formation of secondary particles	Exposure to high levels of ammonia may irritate skin, eyes, throat, and lungs and cause coughing. People with asthma may be more sensitive to breathing ammonia than others. NH_3, like NO_x, contributes to eutrophication and acidification.
Non-methane volatile organic compounds (NMVOCs)	NMVOCs produce photochemical oxidants by reacting with NOx in the presence of sunlight. Anthropogenic NMVOCs are emitted from sources including paint application, road transport, dry cleaning and other solvent uses. Biogenic NMVOCs are emitted by vegetation, with the amounts emitted dependent on species and on temperature.	NMVOCs include a variety of chemicals. Certain NMVOC species, such as benzene (C_6H_6) and 1,3-butadiene, are directly hazardous to human health. NMVOCs are also precursors of ground level ozone.
Carbon monoxide (CO)	CO is emitted due to incomplete combustion. Important sources of CO include road transport, businesses, households, and industry. CO reacts with other pollutants	CO can lead to heart disease and damage to the nervous system. It can also cause headache, dizziness and fatigue.

	producing ground-level ozone.	
Methane (CH_4)	CH_4 is produced by both anthropogenic and natural sources. Significant anthropogenic sources include the agriculture sector (from the enteric fermentation of CH_4 from livestock), the waste sector, and 'fugitive' emissions from coal mining and gas.	Methane is an important greenhouse gas, and is one of the gases controlled under the UNFCCC's Kyoto protocol. At the regional and global scale methane also contributes to the formation of ground level ozone.

Table 1: Facts about air pollutants - source EEA (2014)

Over the past decades, owing to the advance of technology and policy measures to control air pollution, emissions of the main air pollutants in Europe have in fact declined significantly (see Figure 3), resulting in improved air quality across the region.

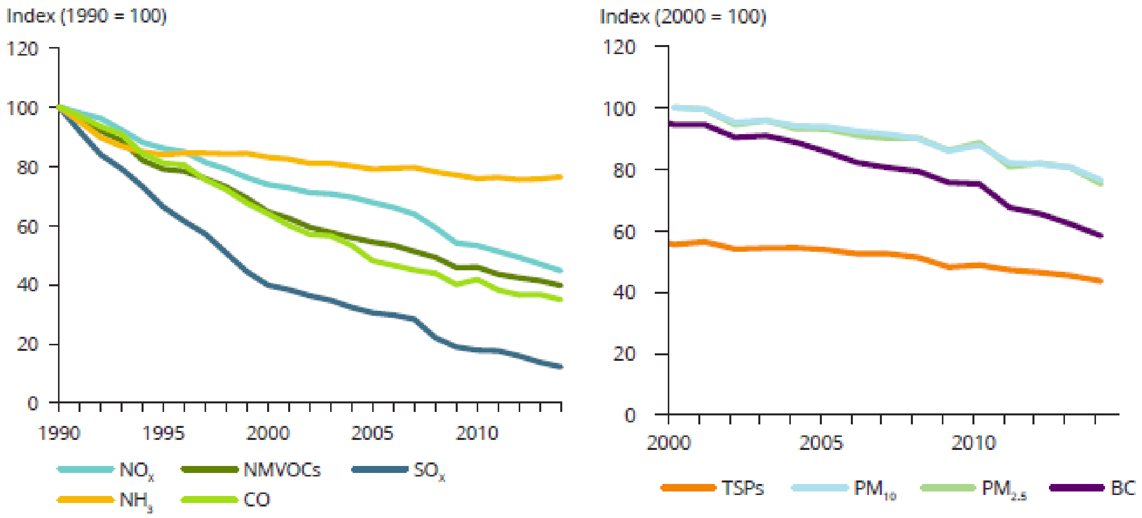


Figure 3: Development in EU-28 emissions between 1990 (2000) and 2014: SO_X, NO_X, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO and BC[3] (EEA, 2016d)

However, certain sectors have not reduced their emissions enough to meet air-quality standards or have even increased emissions of some pollutants, which may result in acute or chronic health effects depending on short-term or long-term exposure to air pollutions. The Ambient Air Quality Directive (EU, 2008) and the WHO (2006) define air-quality standards and guidelines, for the protection of human health. Based on the monitoring data reported by the countries (EEA, 2016a) and the methodology described by EEA (2016e), Table 2 shows the percentage of the EU28 urban population exposed to concentrations above certain EU limit or target values, WHO AQG levels and estimated reference levels between 2012 and 2014 (EEA, 2016b).

[3] Black carbon (BC) is the most strongly light-absorbing component of particulate matter (PM), and is emitted directly into the atmosphere in the form of fine particles ($PM_{2.5}$) – source: EPA

Pollutant	EU reference value (^{a})	Exposure estimate (%)	WHO AQG (^{a})	Exposure estimate (%)
$PM_{2.5}$	Year (25)	8–12	Year (10)	85–91
PM_{10}	Day (50)	16–21	Year (20)	50–63
O_3	8-hour (120)	8–17	8-hour (100)	96–98
NO_2	Year (40)	7–9	Year (40)	7–9
SO_2	Day (125)	< 1	Day (20)	35–49

Key:				
	< 5 %	5–50 %	50–75 %	> 75 %

Notes: (^{a}) In µg/m^3;

The reference concentrations include EU limit or target values, WHO air-quality guidelines (AQGs) and estimated reference levels (RLs).

For some pollutants, EU legislation allows a limited number of exceedances. This aspect is considered in the compilation of exposure in relation to EU air-quality limit and target values.

The comparison is made for the most stringent EU limit or target values set for the protection of human health. For PM_{10}, the most stringent limit value is for 24-hour mean concentration, and for NO_2 it is the annual mean limit value.

Table 2: Percentage of the urban population in the EU28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (2012–2014) adopted from EEA (2016b)

Between 2012 and 2014, about 16% - 21% of the EU28 urban population was exposed to PM10 above the EU daily limit value (i.e. 50 µg/m^3 not to be exceeded on more than 35 days per calendar year, for short-term exposure). Up to 63% of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM10 (annual mean, for long-term exposure) during this period. For $PM_{2.5}$, the Ambient Air Quality Directive introduced a target value of 25 µg/m^3 annual mean to be attained by 2010, which became a limit value starting in 2015. The percentage of the EU28 urban population exposed to levels above the PM2.5 target value was in the range of 8% to 12% in 2012–2014. The urban population's exposure to levels above the more stringent WHO AQG (10 µg/m^3 as annual mean) for PM2.5 fluctuated between 85% and 91% in 2012–2014. Similar to PM_{10}, 2014 saw the lowest percentages of urban population exposure to $PM_{2.5}$ (both the EU target value and the WHO AQG). Current trends indicate that there will still be exceedances in 2020, so more has to be done to reduce concentrations below EU limit values.

For NO_2, it should be noted that there are two limits, set by Ambient Air Quality Directive (EU, 2008) and (WHO, 2006):

1. Annual limit of 40 µg/m^3 (the concentration averaged over a year): no permitted exceedances.
2. Hourly limit of 200 µg/m^3: maximum of 18 exceedances over a year.

About 7% of the EU28 urban population was exposed to NO_2 above the EU annual limit value and the WHO NO_2 AQG value (both 40 µg/m^3 as an annual mean) in 2014. The annual limit value for NO_2 was widely exceeded across Europe, and 94% of all values above the annual limit value were observed at traffic stations in 2014. A total of 17 of the EU28 recorded concentrations above this limit value at one or more stations (EEA, 2016b). The exceedance of the annual short-term NO_2 is a major problem in urban areas. For example, Brixton Road in London breached the NO_2 hourly legal limit for 2017 in just five days (Birkett, 2017).

2.1.1.2 The role of transport in improving air quality

In Europe, transport, industry, power plants, agriculture, households and waste management all contribute to air pollution. A breakdown of contributions to air pollutants from different sectors in the EU-28 is provided in Table 3. Although emissions from transport may not be as great compared to other sectors for the majority of pollutants, population exposure to transport emissions can be much higher since transport emissions usually occur in areas with high population density.

	Energy production and distribution	Energy use in industry	Commercial, institutional and households	Road transport	Non-road transport	Industrial processes and product use	Agriculture	Waste	Other
NO_x	20%	13%	14%	39%	7%	3%	4%	0%	0%
NMVOCs	9%	2%	16%	11%	1%	49%	11%	1%	0%
SO_2	57%	18%	16%	0%	2%	7%	0%	0%	0%
NH_3	0%	0%	1%	1%	0%	1%	94%	2%	0%
$PM_{2.5}$	5%	7%	56%	13%	2%	10%	5%	2%	0%
PM_{10}	6%	5%	40%	12%	2%	17%	17%	1%	0%
CO	3%	13%	46%	21%	2%	11%	3%	1%	0%

Table 3: Emissions by sector in the EU-28 in 2014 (EEA, 2016d)

As shown in Figure 4, significant progress has been made since 1990 with the continued reduction of main air pollutants from the transport sector. However, the transport sector in total is still the largest contributor to NO_X emissions, accounting for 46 % of total EU28 emissions in 2014. It also contributes considerably to PM, NMVOCs and CO emissions.

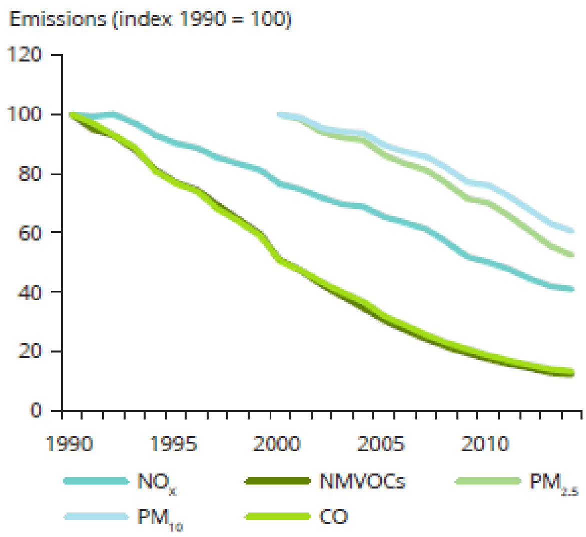


Figure 4: EU-28 emission trends in the sector group 'road transport' between 1990 (2000) and 2014 (EEA, 2016d)

Road transport emissions can be classified into three categories:

Exhaust emissions	The emissions produced primarily from the combustion of different petroleum products such as petrol, diesel, natural gas (NG) and liquefied petroleum gas (LPG). These fuels are mixtures of different hydrocarbons, i.e. compounds that contain hydrogen and carbon atoms. In a 100% efficient engine, oxygen in the air would react in a combustion process with all of the hydrogen in the fuel to form water and with all of the carbon in the fuel to form CO_2, and the nitrogen in the air would remain unaffected. In reality, no combustion process is 100% efficient; therefore, vehicle engines emit many different pollutants in addition to water and CO_2. The amount of each pollutant emitted is dependent on the type of fuel used (diesel or petrol) and engine technology.
Abrasion	The emissions produced from the mechanical abrasion and corrosion of

emissions	vehicle parts. Abrasion results in PM emissions and emissions of some heavy metals. Significant levels of PMcan be generated from the mechanical abrasion of the vehicle's tyres, brakes and clutch, the road surface wear or the corrosion of the chassis, bodywork and other vehicle components.
Evaporative emissions	Evaporative emissions are the result of vapours escaping from the vehicle's fuel system. The majority of evaporative emissions are VOCs. Petrol fuel vapour contains a variety of different hydrocarbons, which can be emitted any time there is fuel in the tank, even when the vehicle is stationary with its engine turned off. Compared to petrol, diesel evaporative emission is small as it is a less volatile fuel.

Table 4: Type of vehicle emissions - source: EEA (2016f)

Exhaust emission can be further classified into “hot” and “cold-start” exhaust emissions. “Hot” emissions are produced when a vehicle’s engine and emission control system is at full operational temperature. On the other hand “Cold-start” emissions, , are produced when a vehicle’s engine and emission control system is between full operational temperature and ambient temperature.

The main pollutant from different types of sources are shown in Table 5, along with whether they are regulated by EU directives.

Source/process	Pollutant(s) emitted	
Hot and cold-start exhaust emissions	Regulated pollutants	CO VOCs NO_x PM
	Unregulated pollutants	
Evaporative emissions	VOCs (regulated)	
Tyre and brake wear Road surface wear Resuspension	PM (unregulated)	

Table 5: Type of pollutants by emission sources (Boulter et al., 2007)

NO_x and PM are the pollutants of greatest interest because of their effect on human health and the challenges faced by different cities to meet EU limits. For example, it is reported that these two pollutants are the principal concern from road transport in London (TfL, 2014a).

Most of the NO_x emissions from road transport are due to the use of diesel vehicles. Although localised variation exists, Figure 5 and Figure 7 are representative examples to show the problem of NO_x emissions that many European cities face. Although light goods vehicles (LGVs - up to 3.5 tonnes) and heavy goods vehicles (HGVs – over 3.5 tonnes) only accounted for 17% of all vehicle kilometres travelled on London’s roads in 2013, they are responsible for more than 30% of road transport NO_x emissions.

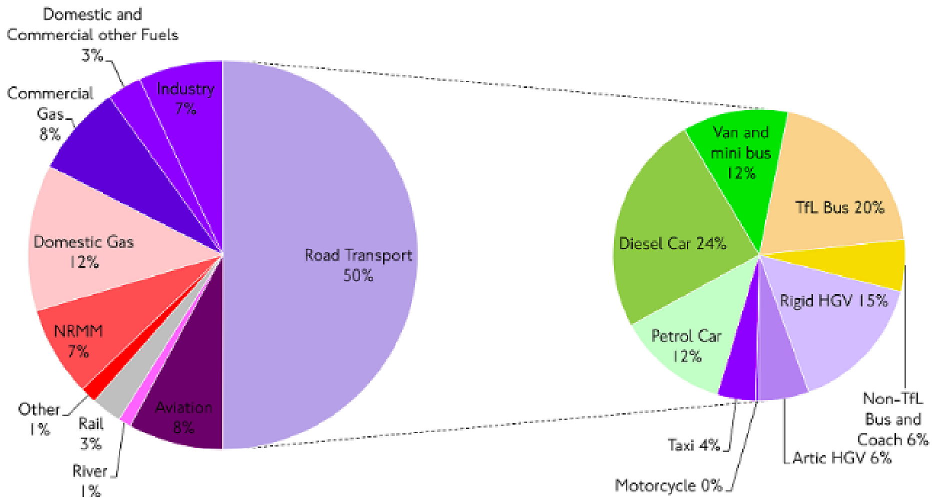


Figure 5: NOx source apportionment in Greater London in 2013 (LAEI, 2013)

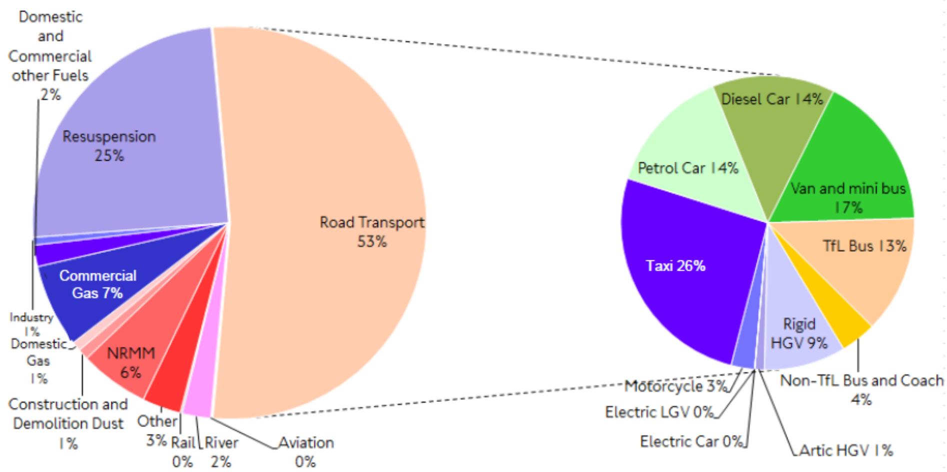


Figure 6: PM_{10} sources in central London in 2013 (LAEI, 2013)

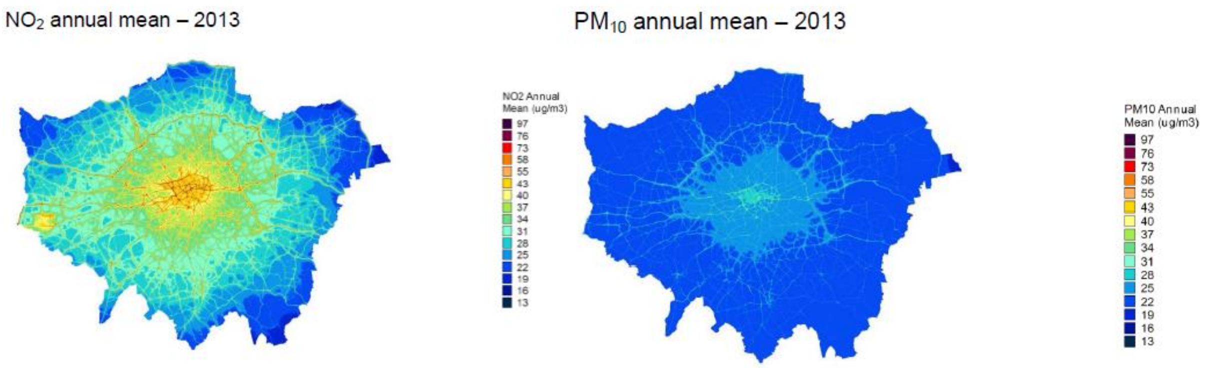


Figure 7: Concentrations of annual average NO_2 and $PM_{2.5}$ in London in 2013 (LAEI, 2013)

As reported by Transport for London (TfL, 2014b), the proportion of both LGV and HGV traffic in London is growing year on year. Car traffic, however, continues to fall, as shown in Figure 8. Despite this, a large part of central London continues to exceed the annual NO_2 limits and this is likely to continue beyond 2020 (see Figure 7). More needs to be done to meet the EU limits by 2020.

For PM emissions in London, similarly to NO_x, road transport contributes to more than half of the total PM_{10} emissions. Out of these, more than 25% stem from freight vehicles. The Department for Environment, Food and Rural Affairs (Defra) in the UK has reported PM compliance across England and Wales in 2015, with most sites in London falling below the legal limits. However, for $PM_{2.5}$, due to the severe negative impacts on health, there are no safe limits. Health evidence suggests that further emission reductions will bring significant improvements in health for Londoners (TfL, 2016b).

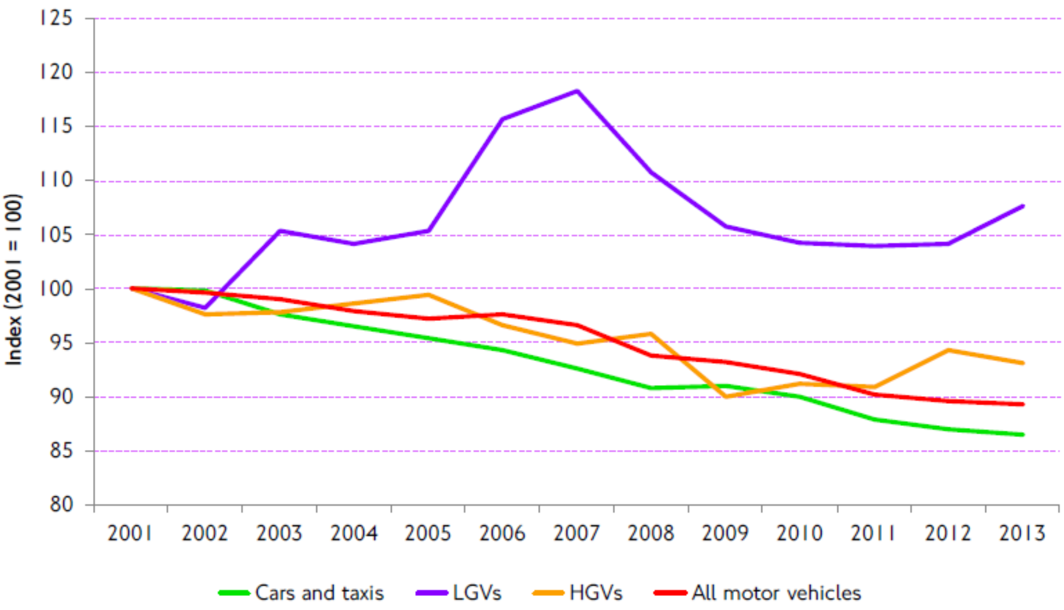


Figure 8: Growth in road traffic in London by vehicle types (2001 – 2013) (TfL, 2014b)

To reduce road transport emissions, EU emission standards for exhaust emissions have become increasingly stringent over the years for both light and heavy duty vehicles. Vehicle manufactures have achieved compliance with decreasing emission limits, mainly by introducing technological solutions, in particular through the gradual implementation of enhanced emission-control technologies such as exhaust catalysts and diesel particulate filters (DPF).

The latest iteration of these standards, Euro VI, has been mandatory for all new heavy duty engines for HGVs and buses since January 2014, whilst Euro 6 has been mandatory from 4 September 2015 for cars and light vans, and September 2016 for larger vans up to 3.5t gross vehicle weight. The Euro VI standard for heavy duty diesel engines reduces the limit for NOx emissions by 77%, whilst continuing to set demanding limits for control of particulates and other gases. The main change of the Euro 6 standard for emissions from light duty cars and vans is a reduction in the limit for NO_x from diesel engines of 55%, whilst the other legislated emissions remain unchanged from the previous Euro 5b standard.

However, for light duty vehicles there is a widening gap between official emission measurements and the average real-world driving emissions for NO_x. This gap has widened in recent years, counteracting the effect of more stringent emission regulations (see Figure 9). Most of the recent studies have concluded that the latest Euro 6 diesel cars are, on average, performing significantly better than Euro 5 vehicles. However Euro 6 vehicles still emit significantly more than the Euro 6 standard of 0.08 g/km (Marner et al., 2016). The reasons for this discrepancy include the outdated measurement procedure used to test vehicles, the optimisation of permitted flexibilities by manufacturers during vehicle testing, and differences in driver behaviour under real driving conditions (EEA, 2016f).

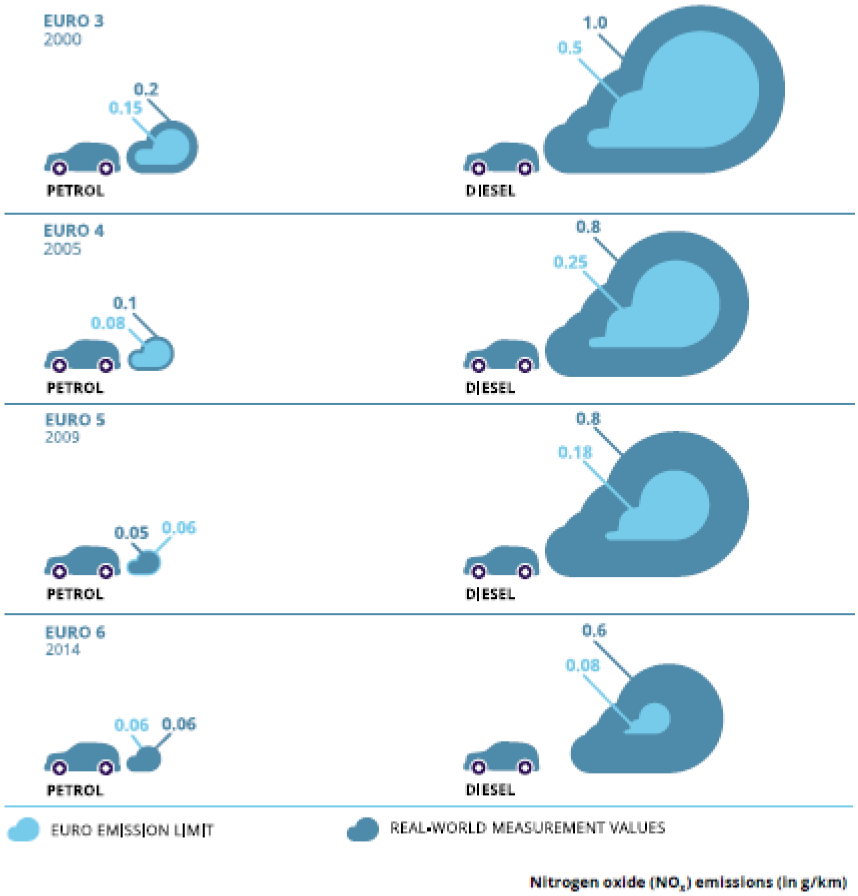


Figure 9: Comparisons of NO_x standards and emissions for different Euro classes (EEA, 2016f)

Tests conducted by Transport for London on HGVs at Euro VI have shown that the NO_x emissions are significantly reduced from vehicles at Euro V. This is especially true at lower road speeds, which is clearly advantageous for urban and suburban areas (TfL, 2015). In a number of cases, these cycle average emission levels are almost as low as those of diesel passenger cars, indicating the effectiveness of Euro VI at controlling NO_x from heavy-duty engines, under the right conditions (Moody and Tate, 2017).

Another test conducted by the LowCVP testing programme (Robinson, 2017), which is funded by Transport for London, shows that despite carrying several times the payload, the Euro VI diesel truck produced similar quantities of NO_x emissions under city centre conditions as the Euro 6 van, but much lower emissions under the urban and regional cycles. Both overall NO_x levels and primary NO_2 emissions are lower. This provides further evidence of the effectiveness of the Euro VI emissions standard.

TNO (2014) also looked at HGV emissions by 'long-haulage' vehicles, and those that operate in an urban environment. They concluded that the picture for real-world emissions was less clear-cut. The six Euro VI long-haulage (extra-urban) vehicles showed very low NO_x emissions compared with Euro V vehicles at both high and low driving speeds. The two urban vehicles also showed an improvement compared with Euro V, but did not perform as well as the long-haulage vehicles. Both TfL and TNO studies show that NO_x emissions were lower with higher payloads, which reflects poorer Selective Catalytic Reduction (SCR) performance at lower temperatures when carrying low payloads.

2.1.1.3 The role of electric vehicles in reducing transport emissions

Electric vehicles charged with low-emission electricity are one of the key options to reduce emissions in road transport. However, the extent to which this may occur varies greatly by country, in terms of how the demand for additional electricity for electric vehicles can be accommodated.

The assessment commissioned by the EEA explored future impacts of greater electric vehicle use upon the EU-28's energy system, and associated emissions from the road transport and energy sectors (EEA, 2016c). Two scenarios were explored:

1. the share of electric vehicles as part of the entire EU-28 car fleet in 2050 was assumed to be 50% (on average)
2. the share of electric vehicles in 2050 was assumed to be 80%.

Increasing the numbers of electric vehicles can significantly reduce direct emissions of CO_2 and air pollutants from road transport. However, these positive effects are partially offset by additional emissions caused by the additional electricity required and continued fossil fuel use in the power sector projection in 2050.

For air pollutants, it is reported that an 80% share of electric vehicles in 2050 will significantly reduce direct exhaust emissions of NO_x, PM and CO_2 from road transport, for each pollutant by more than 80% in comparison with 2010 levels. However, the overall reduction for NO_x and PM will to some degree be offset by additional emissions coming from the electricity-generating sector — by 1% for NO_x and 3% for PM. The situation is different for SO_2. The relatively low SO_2 emissions from road transport, coupled with the use of coal in power generation, will result in additional SO_2 emissions, which exceed the reduction made in the road transport sector by a factor of 5. Additional abatement of the higher SO_2 emissions would be required (EEA, 2016c).

However, the EEA report also pointed out that the difference in emissions of air pollutants from the road transport sector and electricity generation cannot be compared directly in terms of their respective impacts on human health. Their impact depends to a large degree on the location, intensity and type of emission sources. Emissions from road transport occur at ground level and generally in areas where people live and work, such as in cities and towns, so much of the population is exposed to them. In contrast, power stations are generally outside cities, in less populated areas. As a result of this lower exposure, a shift of emissions from the road transport sector to the power generation sector can therefore be beneficial for health.

2.1.1.4 Road transport emission models

In some countries, the modelling of road transport emissions has been undertaken on a national basis for local pollution studies since the 1970s. Over the years, models used to predict exhaust emissions have been improved in terms of type and quantity of data (Barlow and Boulter, 2009). There are many factors affecting vehicle emissions, including:

1. vehicle-related factors, such as vehicle emission standards, model, weight, fuel type, technology level and mileage,
2. operational factors, such as speed, acceleration, gear selection, road gradient and ambient temperature

These factors are considered in all emission models, however, the way in which they are applied can vary substantially.

In Europe, the type of emission model use varies by country, as shown in Figure 10, however most of the European countries use COPERT or COPERT-based models (detailed explanation is given in the following sections).

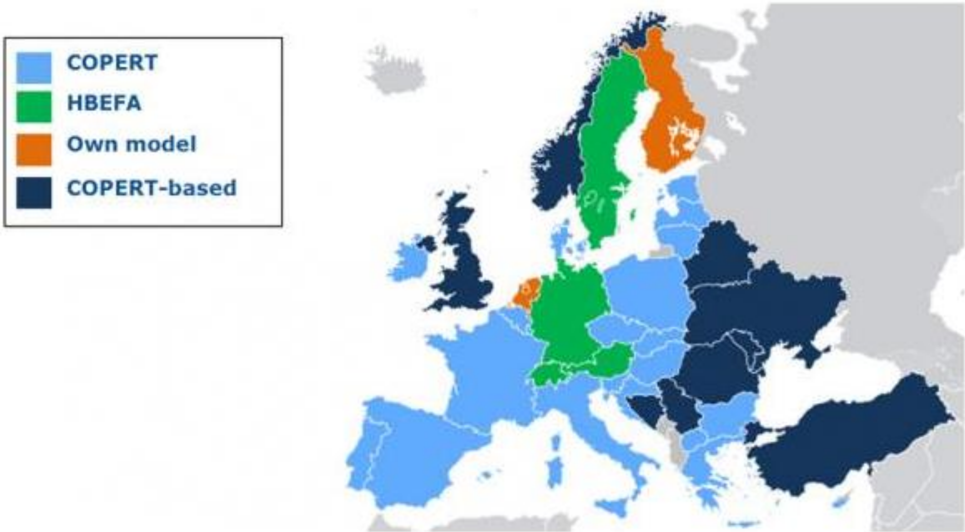


Figure 10: Vehicle emission models usage in Europe (Source: ERMES)

Methods of estimating exhaust emissions tend to be classified based on a combination of the geographical scale of application, the generic model type, and the nature of the emission calculation approach (Barlow and Boulter, 2009). These types of methods can be broadly classified into the following five categories.

2.1.1.4.1 Aggregated emission factor models

Aggregated emission factor models are used at the simplest level. Because vehicle operations are only considered at a rudimentary level, the emission factors are given to represent a particular type of vehicle operating under a specific environment (usually defined as urban roads, rural roads and motorways). Hence this approach cannot be used to calculate vehicle emissions for the situations which are not explicitly defined. The emission factors are usually given in terms of the mass of pollutant emitted per vehicle and per unit distance, or per unit of fuel consumed.

Aggregated emission factor models are mainly applied on a large spatial scale when limited detailed information is available on vehicle operation, such as national or regional emission inventories. They are generally not used for regulated pollutants (such as NO_x and PM) and CO_2 if detailed data is available for more sophisticated approaches. However, they are frequently used in estimating unregulated pollutants as there is insufficient information to define a more detailed relationship with vehicle operation (Barlow and Boulter, 2009).

The European Environment Agency's COPERT model gives a number of aggregated emission factors.

2.1.1.4.2 Average-speed models

Average-speed models are developed based on the principle that the average emission factor for a certain pollutant from a given type of vehicle varies based on the average speed of a trip. They are widely used to estimate hot exhaust emission from road transport, not only by national and regional emission inventories, but also many local air pollution prediction models. Similar to the aggregated emission factor models, the emission factor from average-speed models are also stated in gram per vehicle-kilometre.

The average-speed models have been a popular method because they are relative easy to use, there is also a close correspondence between the required model inputs and the data that is available to the users in reality. The results are also better than the aggregated emission factor models. However, there are some common criticisms about the average speed models, including(Barlow and Boulter, 2009):

1. Trips with very different operation characteristics (hence very different emission levels) can have similar average speed. Therefor it is difficult to use a single average-speed emission factor to represent all types of vehicle operations. This is especially the case at low to medium average speeds where the range of possible vehicle operation conditions is large. Hence the average-speed models usually underestimate these emissions.
2. Modern vehicles are equipped with sophisticated emission control devices. Usually a large percentage of the total emissions are emitted during a number of short and sharp periods, such as during gear changes and periods of high acceleration. However these cannot be reflected in the average-speed emission models.
3. Some also argue that the average speed model is “cycle dynamics”, which means that the models are developed based on the types of test cycle used. For example, each of the cycles used in the development of the average speed model should represent a real-world driving condition, however, the actual distribution of these driving conditions vary by time and location in the real-world.

A number of well-known emission tools are based on this approach, including:

1. COPERT: which has been developed by the European Environmental Agency (EEA) to estimate emissions of all major air pollutants (CO, NO_x, VOC and PM) from road vehicles as well as greenhouse gas emission for the purpose of emissions inventory construction (Gkatzoflias et al., 2012). It contains some of the most widely used average-speed functions and draws its main principles and data from several European activities.
2. ARTEMIS: aims to understand the difference and uncertainty in emission model prediction, hence to develop a harmonised methodology to estimate emissions from all transport modes. It contains emission factors for both traffic simulations and average-speed models.
3. DMRB (Design Manual for Roads and Bridges): DMRB emission inventory approach was developed for the UK’s Highways England (formerly Highways Agency). The method employs average emission rates of five pollutants (including CO, NO_x, HC, PM and CO_2) for light and heavy duty vehicles as a function of average vehicle speed on a link.

2.1.1.4.3 Traffic situation models

The idea of traffic situation model is that cycle average emission rates are correlated with a number of driving parameters in this cycle, which are known to the users. Then the emission factors can be obtained by relating the parameters with the traffic situations defined in the model.

One of the best known traffic situation models is the HBEFA (Handbook of Emission Factors for Road Transport). It is a system for calculating average emission factors for 69 predefined urban and rural traffic situations and their associated 4 defined levels of service for user-specified assumptions of vehicle fleets, climate parameters, road gradients and vehicle load factors. The underlying datasets are based on PHEM (see below). Factors are provided for both regulated pollutants and greenhouse gas emission (North and Hu, 2012).

HBEFA is developed by Environmental Protection Agencies of Germany, Switzerland and Austria and is the model of choice for emission analysis in these three countries.

However, the criticisms of this model include (Barlow and Boulter, 2009):

1. Users have to define the traffic situation based on textual descriptions, which may lead to inconsistencies in analysis
2. There are no universal agreed definitions for traffic situations
3. The parameters in the HBEFA model area are specifically designed for Germany, Switzerland and Austria. Therefore they may not be used directly for other counties

2.1.1.4.4 Multiple linear regression model – VERSIT+

VERSIT+ is an emissions model developed by Netherlands Organization of Applied Scientific Research (TNO). It is a statistical emission model able to calculate real-world NO_x, PM and CO_2 emissions of road vehicles. It is based on a database of 12,000 measured driving cycles, mimicking all aspects of real-time driving behaviour. Using advanced statistical modelling techniques, VERSIT+ finds the best fitting emission factor equation for any given driving pattern. Emissions are then estimated based on the regression results.

A specific implementation of the model (EnViVer; Environmental VISSIM and VERSIT) has been developed for use with the Dutch vehicle fleet and for integration with traffic microsimulation (PTV's VISSIM model initially) (North and Hu, 2012).

2.1.1.4.5 Instantaneous emission model

Boulter et al. (2007) offers good summaries of the instantaneous emission model:

"This type of model aims to provide a precise description of vehicle emission behaviour by relating emission rates to vehicle operation during a series of short time steps (usually at the second level). In principle, instantaneous emission models allow users to calculate emissions for any vehicle operation profile, and therefore new emission factors can be generated without further testing. The models inherently take into account the dynamics of driving cycles, and therefore can be used to explain the variability in emissions calculated using average-speed models. Another advantage is that instantaneous emission models allow emissions to be resolved spatially. However, this type of model requires very detailed vehicle operation and location data, which can be very expensive to acquire in the real world or from traffic models".

There are many types of instantaneous emission models available, including for example, Model of vehicle Emission (MODEM), Digitised Graz Model, Passenger Car and Heavy Duty Emission Model (PHEM), Vehicle Transient Emissions Simulation Software (VeTESS), Comprehensive Modal Emission Model (CMEM), Analysis of Instantaneous Road Emissions (AIRE) etc. A more detailed model descriptions can be found in Boulter et al. (2007) and North and Hu (2012).

PHEM model, which was developed by the Technical University of Graz, is one of the most comprehensive instantaneous emission models and it uses an emission map as a look-up table to estimate emissions. The inputs are user-defined driving patterns and vehicle characteristics. The PHEM model then calculates the actual engine power demand and engine speed for every second of the driving pattern. The engine power and speed are then used to obtain the relevant emission values of steady-state engine maps. The main outputs include the emissions per second of CO, CO_2, HC, NO_x, and PM.

PHEM model covers many different vehicle categories and vehicle emission types, including the use of different emission control technologies and alternative fuels. Although it provides a very detailed spatial and temporal emission distribution map from road vehicles, the drawbacks include that it is very time consuming to run the model, and it also requires substantial detail about the physical characteristics of the vehicle fleet being estimated. Therefore, similar models have been developed to make use of the PHEM emission database and underlying relationships but aggregate the data to more generic vehicle types (North and Hu, 2012).

AIRE is one of these models, and was developed by SIAS limited in collaboration with the Transport Research Laboratory (TRL) in the UK for Transport Scotland. It incorporates over 3,000 Instantaneous Emissions Modelling (IEM) tables which are used to estimate tailpipe emissions from individual simulated road vehicles. The IEM tables were derived from PHEM.

AIRE was designed to work with the outputs directly from traffic microsimulation models and can be used to process the detailed, vehicle by vehicle outputs and provides significantly more disaggregate and detailed emissions estimates compared with traditional, average speed-based methods (Scotland, 2011).

However, at the time of writing this report, most of the instantaneous emission models cannot produce estimations for Euro VI heavy goods vehicles due to the lack of testing data.

2.1.1.5 Analysis strategy

For most of the FREVUE demonstrators, the EFVs are like-for-like replacements for ICEVs. Therefore it is reasonable to assume that abrasive emissions and resuspension pollutants are similar between EFVs and ICEVs if they have the same operational patterns. The emission analysis will therefore be based on exhaust emissions only.

As described in Table 5, there are two types of exhaust emissions: hot and cold-start emissions. Emissions of pollutants are higher during the cold-start phase due to the fact that the engine, catalyst, and drivetrain are not working at their optimal temperature. As a result, there is increased incomplete fuel combustion, increased engine friction and reduced catalyst efficiency. The proportion of cold-start emissions out of total emissions vary by pollutant type. For example, in 2003, 49% of total CO emissions from road transport were emitted during the cold-start periods, but only 10% of total NO_x emissions were due to cold-start engines in the UK (Boulter and Latham, 2009).

Many factors can affect cold-start emissions, including vehicle type, emission control technology, fuel and lubricant properties, average speed, ambient temperature, distance travelled, parking durations and driving cycles.

The effects of cold-start on petrol and diesel vehicles differ significantly. A number of studies, (for example Boulter and Latham (2009), Windeatt et al. (2012)) confirm that in absolute terms, diesel cars and LGVs produce much lower cold-start emissions compared with their petrol equivalents. However in another study (Bielaczyc et al., 2011), it is summarised that petrol cars produce much higher CO and Hydrocarbons (HC), while diesel cars produce high NO_x emissions during cold-start.

There is no current conclusive evidence on emissions for cold-start diesel heavy goods vehicles. This is evident as cold-start emission factors from HGVs are not available in the latest COPERT 4v11 model. Therefore, for this analysis, only hot emissions are calculated.

The estimation of hot emissions depends on the quality and availability of data:

For the demonstrators with dynamic vehicle data, both the COPERT model (using COPERT 4v11) and the AIRE (version 1.0.24115.0) instantaneous emission models were tested. However, it was later discovered that the quality of GPS data was not good enough to have a reliable estimation of instantaneous emissions (more details given in section 2.2.2). In addition, the AIRE model cannot produce Euro VI results for comparison. Hence the average speed approach was used as the method for calculating exhaust emissions. The emission functions used are detailed in the EMEP/EEA air pollutant emission inventory guidebook – 2016 [4], which are also implemented in COPERT 4v11. These functions provide the mathematical equations that relate g/km emission factors to average vehicle speed and vehicle types. Because vehicle load information is not available, 50% load is assumed across all HGV fleets.

For the demonstrators with only aggregate data (no speed data available), the aggregated emission factors are used. These emission factors are derived from COPERT 4v11 and can also be found in the EMEP/EEA air pollutant emission inventory guidebook – 2016. The relevant factors are extracted in Table 6 below.

Type	Vehicle category	sub category	NO_x	$PM_{2.5} = PM_{10}$	FC[5]
			g/km	g/km	g/km
LGV	Diesel <3.5 t	Euro 3 - 98/69/EC I	1.03	0.0783	80
LGV	Diesel <3.5 t	Euro 4 - 98/69/EC II	0.831	0.0409	80
LGV	Diesel <3.5 t	Euro 5 – EC 715/2007	1.18	0.001	80
LGV	Diesel <3.5 t	Euro 6 up to 2017	0.953	0.0009	80
HGV	Diesel <=7.5 t	HD Euro III - 2000	2.63	0.0566	101
HGV	Diesel <=7.5 t	HD Euro IV - 2005	1.64	0.0106	101
HGV	Diesel <=7.5 t	HD Euro V - 2008	0.933	0.0106	101
HGV	Diesel <=7.5 t	HD Euro VI	0.18	0.0005	101
HGV	Diesel 7.5 - 16 t	HD Euro III - 2000	4.3	0.0881	155
HGV	Diesel 7.5 - 16 t	HD Euro IV - 2005	2.65	0.0161	155
HGV	Diesel 7.5 - 16 t	HD Euro V - 2008	1.51	0.0161	155
HGV	Diesel 7.5 - 16 t	HD Euro VI	0.291	0.0008	155
HGV	Diesel 16 - 32 t	HD Euro III - 2000	6.27	0.13	210
HGV	Diesel 16 - 32 t	HD Euro IV - 2005	3.83	0.0239	210
HGV	Diesel 16 - 32 t	HD Euro V - 2008	2.18	0.0239	210
HGV	Diesel 16 - 32 t	HD Euro VI	0.422	0.0012	210

Table 6: Exhaust emission factors for LGV and HGV (Tier 2 analysis – Source: EMEP/EEA Emission Inventory Guidebook – 2016)

The change of exhaust emissions is calculated by comparing the hot exhaust emissions from EFVs against the hot exhaust emissions from their diesel equivalents, assuming the same driving cycle and operational arrangements. However the results are presented by different diesel vehicle technology (emission standards) for the purpose of generalisation. Therefore the operators can quantify the environmental benefits EFVs can bring comparing with newer Euro 6/VI vehicles. Comparisons are only made to Euro 3/III vehicles and above due to the fact the oldest vehicle which was replaced by an EFV in this study was a Euro 3/III vehicle.

[4] Under Part B, section 1.A.3.b.i-iv: http://www.eea.europa.eu/publications/emep-eea-guidebook-2016/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion
[5] FC: Fuel consumption

2.1.2 Impacts on CO_2 emissions

2.1.2.1 Background

As defined by the IPCC (2008), greenhouse gases are gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and fluorinated gases are the primary greenhouse gases in the Earth's atmosphere.

According to the EEA, over 80% of GHG emissions in the EU-28 stem from carbon dioxide (CO_2), as shown in Figure 11. CO_2 enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees and wood products, and also as a result of certain chemical reactions. Carbon dioxide is removed from the atmosphere when it is absorbed by plants as part of the biological carbon cycle.

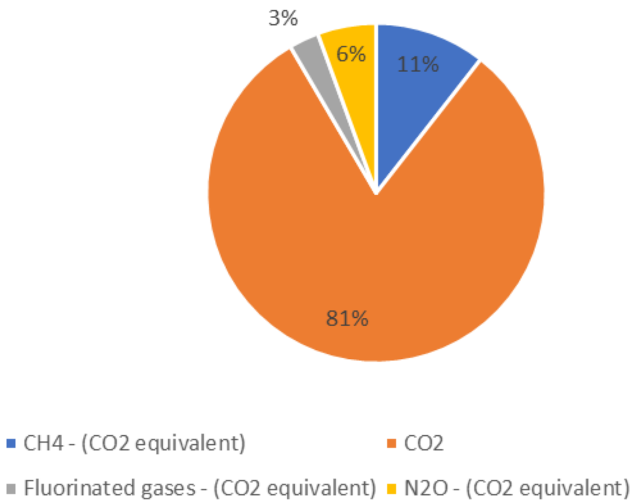


Figure 11: Share of total greenhouse gases in the EU28 in 2014 (source: EEA)

Different gases have different capacities to cause global warming, depending on their radiative properties, molecular weight and the length of time they remain in the atmosphere. "Global warming potential" (GWP) is used to describe the amount of warming a gas causes over a period of time. GWP is an index, with CO_2 having the index value of 1, and the GWP for all other GHGs is the number of times more warming they cause compared to CO_2. Carbon dioxide equivalent (CO_2e) is used to report different greenhouse gases in a common unit, calculated based on the GWP index value.

Greenhouse Gas		Global Warming Potential (GWP)
1.	Carbon dioxide (CO_2)	1
2.	Methane (CH_4)	25
3.	Nitrous oxide(N_2O)	298
4.	Hydrofluorocarbons (HFCs)	124 – 14,800
5.	Perfluorocarbons (PFCs)	7,390 – 12,200
6.	Sulfur hexafluoride (SF_6)	22,800
7.	Nitrogen trifluoride (NF_3)[3]	17,200

Table 7: Kyoto Gases and their GWP value over a 100-year period (IPCC, 2007)

Due to the negative effects of GHG, many governments and organisations have set out their plans to reduce the GHG emissions. For example, the EU has committed in cutting its emissions by 20 % below 1990 levels by 2020. This commitment is one of the headline targets of the Europe 2020 growth strategy, known as the Climate and Energy package (EEA, 2016g). The main policy instruments to achieve this target are the EU Emissions Trading System (EU ETS) and the Effort Sharing Decision (ESD). Looking beyond 2020, the EU has set the target of reducing GHG emissions by 40% below 1990 levels by 2030, and aim to reduce it further by 80% below 1990 levels by 2050.

Between 1990 and 2014, GHG emissions in the EU-28 have been reduced by 22.9%, representing a reduction of 1136 million tonnes of CO_2e, putting EU on track to surpass its 2020 target (EEA, 2016g).

2.1.2.2 The role of transport in reducing GHG emissions

As shown in Figure 12, transport has increased its contribution to overall GHG emissions significantly since 1990. This is further demonstrated in Figure 13 which clearly shows that transport (including aviation but excluding maritime transport) is the only sector with increased GHG emissions in 2014 comparing to its 1990 levels, despite a decline between 2008 and 2013. There is an increase of 0.7% between 2013 and 2014, mainly due to higher emissions from road transport.

Within the transport sector, road transport is by far the biggest emitter, accounting for more than 72% of GHG emissions. Out of emissions in road transport, 44 % were contributed by passenger cars, while 18 % came from heavy-duty vehicles (EEA, 2016h). In total, trucks, buses and coaches (collectively called heavy duty vehicles - HDVs) produce around 5% of the EU's total greenhouse gas emissions.

Although there have been some improvements in fuel efficiency, due to increased road freight traffic, GHG emissions from HDVs rose by 36% between 1990 and 2010. Based on current projections, total HDV GHG emissions would stay close to the current levels in 2030 and 2050 without policy intervention (EEA, 2016j).

According to the 2011 Transport White Paper[6], emissions from the transport sector needs to be reduced by two thirds by 2050 in order to meet the long-term 80% GHG emission reduction target compared to 1990 levels.

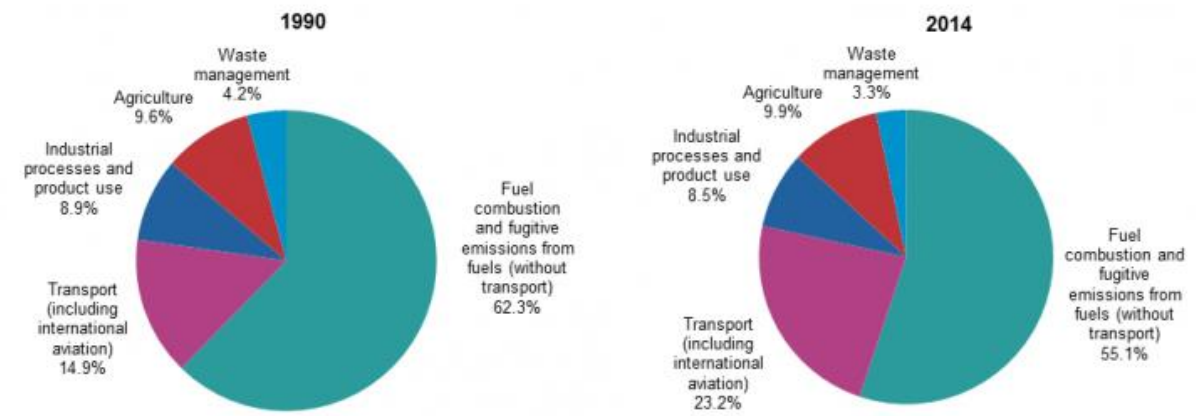


Figure 12: Greenhouse gas emissions, analysis by source sector, EU-28, 1990 and 2014 - percentage of total (EEA, 2016g)

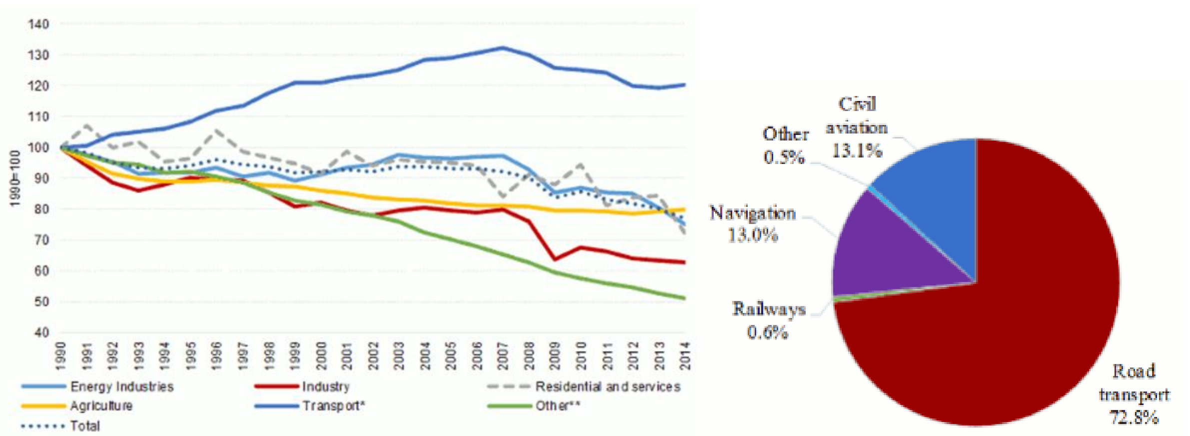


Figure 13: Left: the trend of GHG emissions by sector from 1990 to 2014 in the EU-28 Right: GHG emissions from transport by mode in 2014, EU-28 (exclude: maritime) Source: EEA (2016h)

This poses significant challenges. Based on EEA (2016f), two important regulations have been introduced in recent years for new passenger cars and light commercial vehicles (LGVs) sold in Europe. These legislations set mandatory limits on average CO_2 emissions from newly-registered cars and LGVs in order to reduce CO_2 emissions. For example, by 2021, the average emission to be achieved by all new cars is 95 g CO_2/km and for LGVs this is 147 g CO_2/km.

Similar legislation is being considered and consulted for HDVs. According to EEA (2016j), the HDV strategy which was adopted in 2014, focused on short-term action to certify, report and monitor HDV emissions. The EC has developed a computer simulation tool to measure CO_2 emissions from new vehicles. With the support of this tool the Commission intends to propose legislation which would require CO_2 emissions from new HDVs to be certified, reported and monitored. This legislation is currently under public consultation.

[6] https://ec.europa.eu/transport/themes/strategies/2011_white_paper_en

There are other ways to reduce GHG emission from freight transport, such as improving fleet design, better driving training and in-cab technologies, reducing road miles and using low and zero emission technologies. For further information on such initiatives refer to the Freight Carbon Review report published by the Department for Transport in the UK (DfT, 2017).

2.1.2.3 The role of electric vehicles in reducing freight transport GHG emissions

The principal advantage of battery electric freight vehicles (EFV) is that they are zero-emission at point-of-use. EFVs therefore provide environmental benefits in terms of local air quality pollutant reductions but will only provide climate change benefits if the GHG emissions from generating the electricity, this production is important to consider this when comparing the benefits they consume are less than those from combusting the diesel fuel used by the conventional diesel vehicles they replace.

In countries with high proportion of fossil fuel power plants or carbon-intense electricity imports, electric vehicle demand could lead to higher CO_2 emissions. Zivin et al. (2014) analysed the marginal emissions of electricity demand by location and time of day across the United States, they found that the CO_2 emissions vary significantly based on the locations and times of the day. For example, in the western United States and Texas, there is a net benefit in terms of CO_2 reduction by driving a pure electric vehicle (PEV) rather than driving a hybrid car. However, in the upper Midwest, charging vehicles at night would lead to more CO_2 emissions per mile than the average car currently on the road.

In the UK, based on the testing LowCVP (Robinson, 2017) did on a 2.2t pure electric van and a 7.5t electric HGV with range extender (operating in battery mode). Both vehicles have GHG savings around 30-40% for urban and regional cycles, and 60% for city centre cycles, based on the UK average carbon-intensity of grid electricity.

According to EEA (2016i), the share of low-carbon energy sources (renewables and nuclear energy) in all gross electricity generation has increased significantly. In 2014, they are generating more power than fossil fuel sources. The renewables sources have increased their share from 13% in 1990 to 29% in 2014, while the share of nuclear energy decreased slightly from 31% in 1990 to 28% in 2014. Fossil fuels are responsible for 42% of all gross electricity generation, a reduction of 25% from the 1990 percentage levels. Figure 14 presents the amount of electricity production by fuel type in the EU-28.

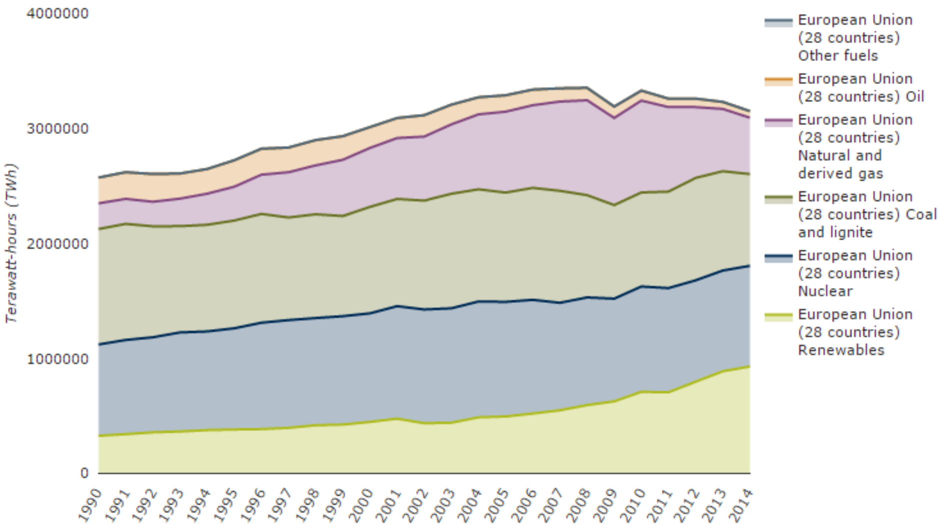


Figure 14: Gross electricity production by fuel in the EU-28 (EEA, 2016i)

Due to the increased share of low-carbon energy sources, the carbon intensity of total electricity generation in the EU-28 has decreased by more than 36% from 1990 to 2014 (from 431 gCO_2/kWh in 1990 to 276 gCO_2/kWh respectively). However, member countries vary significantly. For example, the carbon intensity of electricity generation can be as high as 830 gCO_2/kWh in Greece, and can also be as low as 10 gCO_2/kWh in Sweden. Therefore, the potential benefits of CO_2 savings vary significantly across European countries depending on where the vehicles are charged.

In the EC's 2050 roadmap for energy report[7], the power sector has the biggest potential for cutting emissions. The aim is to achieve a CO_2 emissions free power sector by 2050, which in turn would significantly improve the CO2-emission reductions from electric vehicles.

2.1.2.4 Modelling GHG emissions

Exhaust GHG emissions are usually calculated based on fuel consumption. These can be calculated using aggregated emission models, average speed models or instantaneous models, as discussed in section 2.1.1.4 Road transport emission models. Most of the methods are either able to derive the CO_2e emission factors directly, or to calculate the amount of CO_2e emitted as part of the calculation.

However, due to the fact that the total environmental benefits of EFVs are directly related to how electricity is generated, the analysis on GHG emissions will be carried out at two levels – local and total environmental load (to consider both direct and indirect emissions).

Based on data availability of the state of charge data (SoC) and vehicle telematics data from different demonstrators, methods used in calculating GHG emissions are different. This is shown in Figure 15.

The calculation of total CO_2 environmental load depends on the availability of the state of charge (SoC) parameters. Without SoC, CO_2 emissions from electricity generation cannot be calculated. It should also be noted that when calculating total environmental load, a well-to-wheel approach is used to make sure the emissions associated with all the stages of fuel/electricity production, distribution and consumption are considered. The well-to-wheel approach is often broken down into two stages:

- Well-to-tank (WTT, also called the "upstream" stage, or indirect emissions): is an average of all the GHG emissions released into the atmosphere from the production of a fuel or energy vector. For the case of petrol/diesel fuel, this includes the emissions associated with extraction, refining and transportation of the raw fuels before they are used to power the transport mode. For the case of electricity, this includes emissions of extraction, refining and transportation of primary fuels before their use in the generation of electricity, and also the emissions during electricity generation and grid losses due to electricity transmission and distribution.
- Tank-to-wheel: (TTW, also called the "downstream" stage, direct or exhaust emissions) is the GHG emissions from the actual combustion of fuel to move the vehicle. These GHG factors will be calculated based on COPERT4 v11 methodologies. The average speed approach or the aggregated emission factors are

[7] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2050-energy-strategy

used depending on the availability of dynamic vehicle data. For EFVs, these emissions are zero.

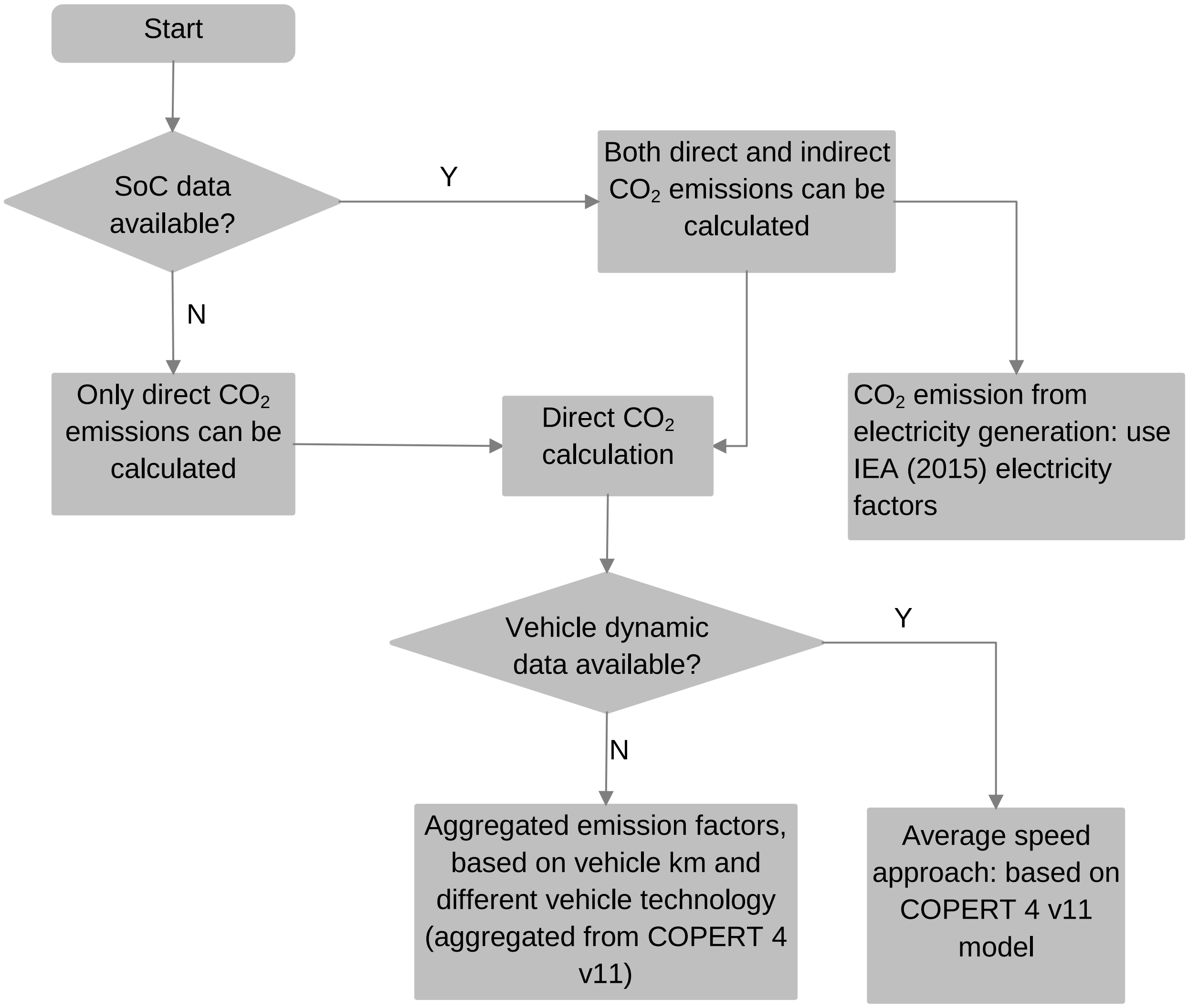


Figure 15: Method selection for GHG emissions calculation

The WTT GHG emission factors of electricity are sourced from DECC/Defra[8] (now only available through IEA[9]) for the year 2015 and are listed in the following table. There might be some differences of these factors between 2014 and 2016 when FREVUE vehicles are operational, but the differences are expected to be minimal.

Year: 2015	unit	Generation ($kgCO_2e$)	Transmission & Distribution Losses (T&D) ($kgCO_2e$)	WTT from Generation ($kgCO_2e$)	WTT from T&D ($kgCO_2e$)	Total emission ($kgCO_2e$)
UK	kWh	0.46219	0.03816	0.06888	0.00569	0.57492
Netherland	kWh	0.39895	0.01682	0.06131	0.00258	0.47966
Italy	kWh	0.39899	0.02824	0.06131	0.00434	0.49288
Norway	kWh	0.01372	0.00142	0.00211	0.00022	0.01747
Spain	kWh	0.28908	0.03089	0.04442	0.00475	0.36914
Sweden	kWh	0.0165	0.00142	0.00254	0.00022	0.02068
Portugal	kWh	0.28271	0.02878	0.04345	0.00442	0.35936

[8] https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting
[9] http://www.iea.org/statistics/relateddatabases/co2emissionsfromfuelcombustion/

Table 8: Grid Electricity GHG Emission Factor by country of FREVUE demonstrations

It should be noted that, in theory, the SoC data should be different to the metered electricity data due to battery and charging efficiency. According to Helms et al. (2010), the efficiency of battery and charger is 95% and 90% respectively for a pure battery electric vehicle. For the FREVUE vehicles, this type of input is not measured. However, it is not unreasonable to assume similar numbers should also apply, although there will be local variations due to different charging technologies. Therefore, to calculate the electricity meter data, the electricity consumption data derived from SoC is then further divided by 0.9 to account for the energy loss of the charger.

Additionally, COPERT 4v11 methods used in this analysis only produces fuel consumption data based on vehicle activities. To estimate CO_2 emissions from fuel consumption, the fuels conversion factors are applied. The following factors are extracted from DECC's UK GHG inventory - conversion factors 2015[10]:

Liquid Fuels	units	Volume (kg CO_2e)	Tonnes (kg CO_2e)
Diesel (average biofuel blend)	litres	2.5839	
	tonnes		3090.3
WTT – Diesel (average biofuel blend)	litres	0.5811	
	tonnes		691.0
Combined	litres	3.1650	
	tonnes		3781.3

Table 9: Diesel fuel CO_2 conversion factors

Unlike electricity which varies significantly (as shown in Table 8) from country to country, diesel is produced to a very similar standard of quality across Europe with minor variations, although at local levels, different amounts of biofuel may be blended in (Defra, 2015). Therefore, it is reasonable to assume that diesel fuel CO_2 conversion factors listed in Table 9 apply to all FREVUE cities.

Similarly to the analysis of pollutant emissions, the change of GHG emissions are calculated by comparing GHG emissions from EFVs against the emissions from their diesel equivalents, assuming the same driving cycle and operational arrangements. Although fuel consumption (or GHG emissions) are not directly related to vehicle technology used (i.e. emission standards), the results are still presented by different diesel vehicle technology for simplification.

2.1.3 Impacts on noise

2.1.3.1 Background

It is reported that road traffic noise is the greatest source of traffic noise both inside and outside urban areas in Europe. The number of people affected by different types of traffic noise is shown in Figure 16. Two of the main indicators used for monitoring noise levels are L_{night} and L_{den} (day–evening–night). L_{night} is the average sound level measured overnight between 23.00 and 07.00. L_{den} is a weighted noise level measured over a 24-hour period,

10 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2015

with a decibel penalty being added to night time noise levels; these penalties reflect people's greater sensitivity to noise during the night and the evening.

Figure 16 shows that in 2012, nearly 90 million people inside urban areas were exposed to long-term average traffic noise exceeding 55 dB L_{den}, and another 35 million people outside urban areas were exposed to the same level of noise. At night, almost 60 million people were exposed to road noise level exceeding 50 dB L_{night} inside urban area and another 23 million people outside urban area exposed to the same level of noise.

High levels of noise harm human health and well-being. There is growing evidence on the links between environmental noise, defined by the World Health Organisation (WHO) as 'noise emitted from all sources except industrial workplaces', and health outcomes. The 2011 WHO report "Burden of disease from environmental noise"[11] identified environmental noise as the second largest environmental risk to public health in Western Europe. A study commissioned by EC on the Health implication of road, railway and aircraft noise in the European Union found that exposure to noise in Europe contributes to about 910,000 additional prevalent cases of hypertension, 43,000 hospital admissions per year, and at least 10,000 premature deaths per year related to coronary heart disease and stroke. A number of papers have been published recently to identify the connection between long-term exposure to traffic noise and health impacts, (Alimohammadi et al. (2013) ,Welch et al. (2013) and Schlittmeier et al. (2015)).

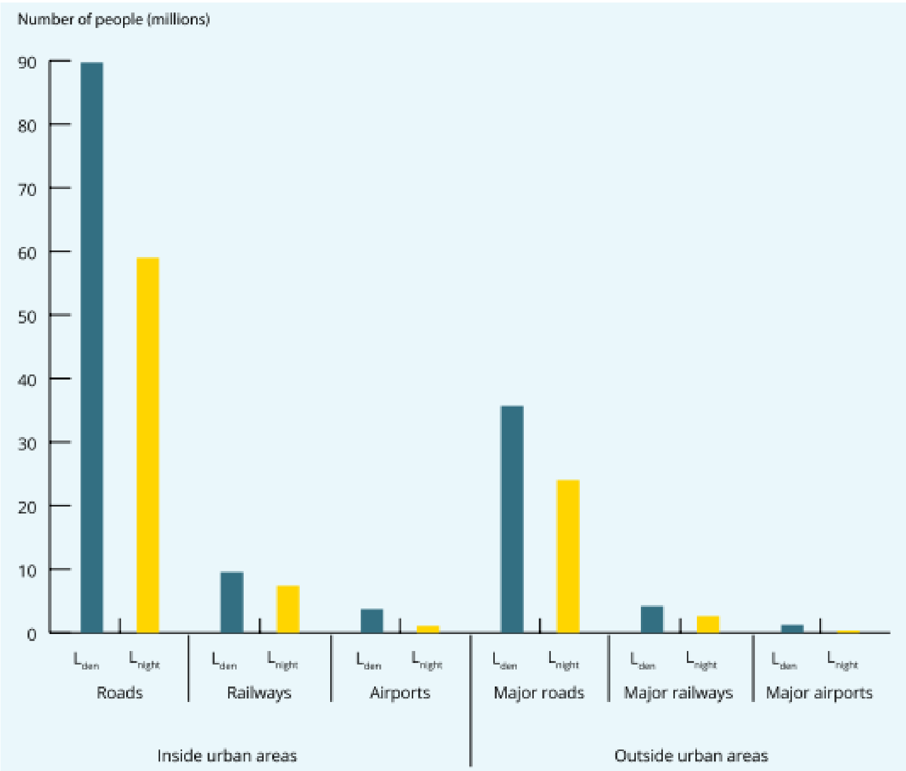


Figure 16: Number of people affected by traffic noise in Europe in 2012 (EEA, 2016f)

Directive 2002/49/EC (the Environmental Noise Directive – END) is the main EU instrument to assess and manage noise pollution levels and to trigger the necessary action both at Member State and at EU level. It requires member states to prepare and publish noise maps and noise management action plans every 5 years for major roads, railways and airports.

11 http://www.who.int/quantifying_ehimpacts/publications/e94888/en/

However, it does not set limit or target values, or prescribe the measures to be included in the action plans. Therefore, those issues are left at the discretion of the Member State authorities to be dealt with.

2.1.3.2 Impacts of EFVs on road traffic noise exposure

Many factors can affect road traffic noise exposures. These factors can be broadly divided into five categories including:

1. Vehicle related parameters: such as engine type, tyre type, vehicle weight and vehicle load.
2. Traffic related parameters, such as vehicle speed, traffic volumes, traffic flow composition, and driving behaviour.
3. Road parameters, including gradients, degree of curvature, type of road surface, road design (such as speed humps, tunnels, cuts and embankments).
4. Geo-spatial parameters, including distance and the presence of buildings, trees, and other obstacles from roads to the recipient of noise.
5. Weather conditions, including wind direction, wind speed, and precipitation.

Out of these parameters, in a like-for-like replacement scenario, the deployment of EFVs in theory should only reduce the engine noise (also called propulsion noise) parameters. The general perception of noise impact from electric vehicles is that the propulsion noise of electric vehicles is much lower compared to vehicles with a combustion engine. However perceived noise level is also greatly affected by speed of the vehicle.

In a study conducted in France in 2012, noise emitted from electric, hybrid dual-axel trucks and an ICE equivalent truck were measured at 7.5m from the centre of the road where the trucks are being tested. It concluded that at low speed (20 km/h), the noise difference between the electric and ICE truck is around 10 dB, however, at a higher speed of 50 km/h, the difference is only 1dB.

A Dutch study (de Graaff and van Blokland, 2011) compares the noise emitted from an electric truck with an ICE truck. Their results show a similar trend – the noise reductions from an EFV is significant at a lower speed. However, as speed increases, the noise difference between EFV and ICEV reduces significantly as the road/tyre noise takes over. They also produced a plot on the relationship between the noise of the vehicle (measured at 7.5 meter from the centre of the test track) and speed of the vehicle (Figure 17).

Apart from the noise sound levels, the frequency contents of noise from EFV and ICEV are also different, which are caused by the different ways a combustion engine and an electric engine function. The difference of noise frequency can be perceived very differently by affected people. It is reported that some electric vehicles emit single tones which many people think is more disruptive than noise with different frequencies (such as combustion engines). For further information on this topic refer to a literature review by (Marbjerg, 2013).

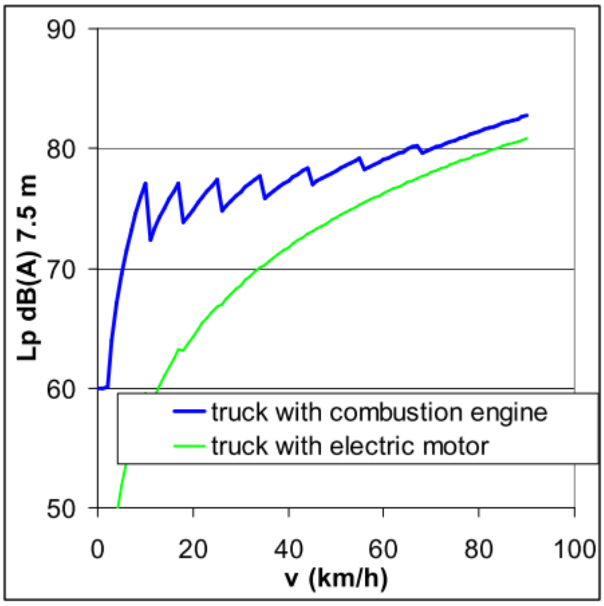


Figure 17: Noise comparison between EFV and ICEV at different vehicle speeds (de Graaff and van Blokland, 2011)

Within the FREVUE project, impacts on noise nuisance are difficult to quantify due to the small scale of the deployments and the large number of factors which contribute to noise profiles within a city. However, FREVUE Rotterdam has conducted a separate study on the acoustic benefits from urban freight traffic electrification based on the 9 traffic light intersections, traffic flow and property location data in the city of Rotterdam[12]. Their results show that there was a reduction of 1 to 2 dB in noise exposure on the electrification of freight vehicles. 399 dwellings (918 inhabitants) would benefit from an additional noise reduction of 0.5 to 1 dB. For 80 dwellings (194 inhabitants) within the intersection's vicinity the additional noise level reduction would be 1 to 1.5 dB.

2.2 Data Overview

2.2.1 Data availability

The data requirements for each of the tasks in WP3 were consolidated at the early stage of the project to improve the clarity of data collection and reduce the burden on the demonstrators by avoiding repeated similar data requests.

As a result, most of the data required for this analysis has been collected by research partner SINTEF, in coordination with Imperial College. Detailed technical analysis on the vehicle data can be found in Deliverable 3.1 Technical Suitability of EVs for Logistics (SINTEF, 2017).

In summary, as shown in Table 10, data was collected from a total of 105 electric freight vehicles. Out of these vehicles, 96 provided the state of charge (SoC) data which allow a well-to-wheel analysis for total GHG emissions. 40 vehicles also provided dynamic vehicle data which means the average speeds can be calculated for each trip. COPERT 4v11 speed-based functions were used to calculate direct NO_x, PM and CO_2 emissions. For the remaining vehicles without vehicle dynamic data, the COPERT 4v11 aggregated factors were used.

[12] http://frevue.eu/wp-content/uploads/2016/06/Acoustic-benefits-from-electrification-of-urban-freight-FREVUE-website-version-.pdf

Operator	No of vehicles	Veh with SoC data?	Veh with Dynamic data?	No of Veh days	Total distance (km)
Italy, Milano, AMAT	1	No	No	85	5651
Netherlands, Amsterdam & Rotterdam, TNT	7	Yes	Yes	1613	123028
Netherlands, Amsterdam, Heineken	6	Yes	Yes	460	22534
Netherlands, Rotterdam, EMOSS	2	Yes	Yes	482	33167
Netherlands, Rotterdam, Heineken	6	Yes	Yes	1157	72786
Netherlands, Rotterdam, Operator 1	8	Yes	Yes	274	20640
Netherlands, Rotterdam, Operator 2	1	Yes	Yes	0	0
Netherlands, Rotterdam, Operator 3	1	Yes	Yes	297	13902
Netherlands, Rotterdam, UPS	4	Yes	No	1389	63140
Norway, Oslo, Bring	5	Yes	Not available to Imperial	2063	180415
Portugal, Lisbon, CTT	15	Partially	Partially	287	12517
Portugal, Lisbon, EMEL	1	No	Yes	91	6172
Spain, Madrid, Calidad Pascual & SEUR & TNT	4	Yes	Yes	912	43688
United Kingdom, London, Clipper	1	Not reliable	Yes	120	1932
United Kingdom, London, UPS	43	Yes	No	5194	162920
Total	**105**	**96**	**40**	**14424**	**762491**

Table 10: Overview of data availability

2.2.2 Data cleaning

Environmental impact calculations are sensitive to the following parameters:

- Distance
- Electricity consumption
- Speed (averaged over a trip)

Therefore, a detailed and rigorous data cleaning process was carried out, with emphasis on these three parameters. The following section explains the cleaning process. The raw data used in this section for demonstrative purpose is from Rotterdam Operator 1 and Amsterdam/Rotterdam TNT.

<u>Data cleaning on distance</u>

Distance data is provided to the research partners in two formats, dependent on the availability of dynamic vehicle data. If dynamic vehicle data is not available, manual recordings from vehicle odometers are used. Data cleaning was completed on this type of data was done by making sure the numbers were all positive and reasonable.

For those partners who provided dynamic vehicle data, the distance for a trip was available from either odometer readings, distance derived from GPS coordinates readings or speed readings.

For the eight vehicles from Rotterdam operator 1, Figure 18 plots a comparison of all three data sources. The x-axis is the odometer readings and y-axis is the derived distance from GPS and speedometer. The data is verified for accuracy using a ‘best fit’ line, plots that deviate from this line show inaccurate readings

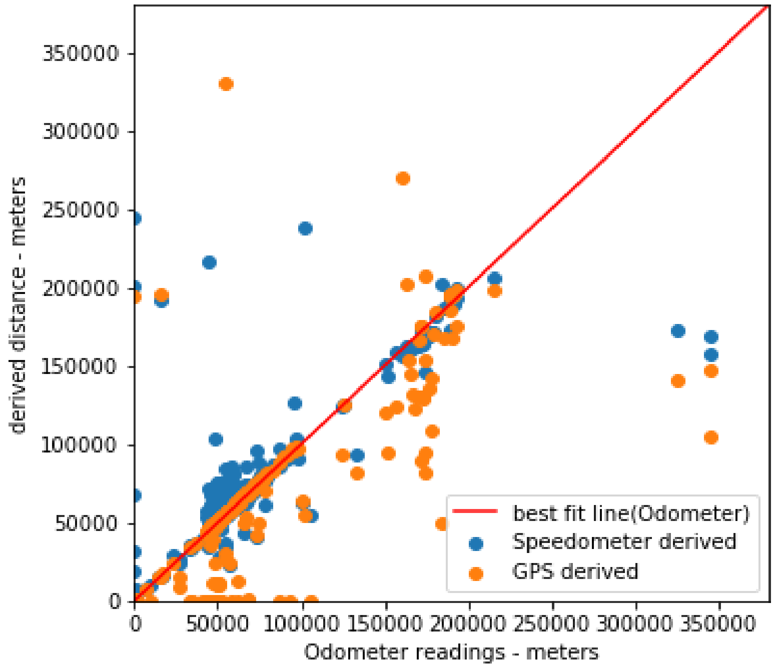


Figure 18: Distance comparison (odometer, GPS distance and speedometer derived distance) – Rotterdam operator 1

From Figure 18, it can be observed that a number of GPS readings provide fairly unstable readings. The GPS data quality is known to be affected by a number of factors, including the GPS receiver, position of satellites and user's location (Open Street Map, 2016), especially in an urban environment where the tall buildings can easily block or "bounce" the GPS signal.

The readings derived from the speedometer tend to overestimate the distance (blue dots above the red line). This can be explained by the Motor Vehicles (Approval) Regulations 2001[13] that by law, a speedometer must never show less than the actual speed, and must never show more than 110% of actual speed + 6.25mph.

This comparison has been done for all the operators who provided dynamic vehicle data. The conclusion from these comparisons found that the odometer is the most accurate source for distance and is therefore used to obtain trip distance data.

<u>Electricity consumption data</u>

All electricity consumption data is provided in the format of state of charge (SoC). However two types of SoC are provided:

- SoC provided is aggregated to the trip level
- SoC provided as a part of the dynamic vehicle data

If SoC is provided at the aggregated trip level, this data are usually manual readings of SoC before and after a trip is carried out. This type of SoC only requires a minimal level of checking, to make sure that all SoC are valid.

[13] http://www.legislation.gov.uk/uksi/2001/25/contents/made#sch3

If SoC is provided as a part of dynamic vehicle data, it usually requires very careful cleaning due to poor data quality.

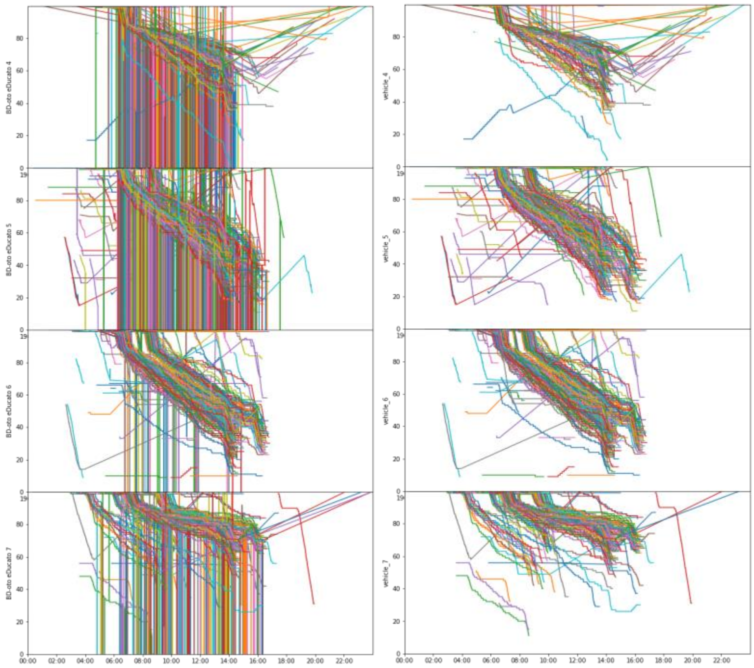


Figure 19: SoC cleaning – left: before cleaning; right: after cleaning (TNT data)

Figure 19 shows an example of the state of charge data at the second level from 0:00 to 23:59 for each of the four electric freight vehicles from Amsterdam TNT. The x-axis is the time of the day and y-axis is the state of charge in percentage format. The left plot is the SoC data before cleaning. As observed, there are many vertical lines, which means the SoC suddenly drops to zero or increases to a high level due to abnormal readings. If the data is used directly without cleaning, it would significantly overestimate the electricity consumption.

The plot on the right shows the SoC data after data cleaning. The cleaning is carried out based on the calculation of electricity consumption per second. If there is a sudden change (of more than 2% of total battery capacity per second) then the data entry is removed.

<u>Speed data</u>

The average speed for a trip is calculated on the speedometer readings. The following plot shows the range of speedometer readings. The quality of data in general is very good. However, there are some abnormally high readings can still be observed.

For the cleaning of speed data, any value above 140km/h was removed.

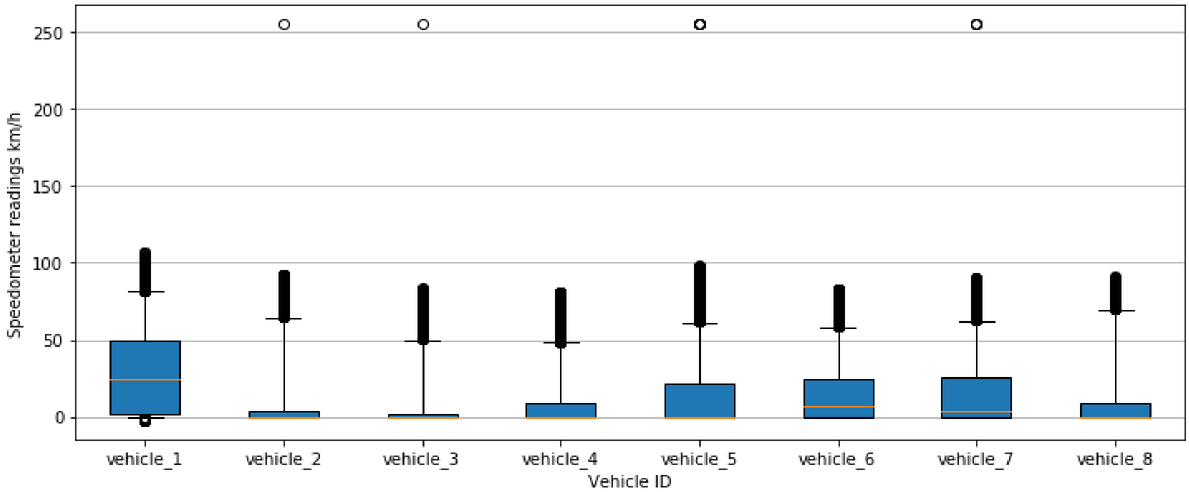


Figure 20: Speed data without cleaning (example: Rotterdam operator 1)

The following sections report the results from environmental impact analysis based on the FREVUE demonstration cities. For each city, comments and analysis are only made on the statistics which are relevant to environmental impacts. For detailed explanation of the operational models and logistic settings, further information is in D3.2 Economics of EVs for City Logistics (TNO, 2017).

2.3 Systemic and environmental impacts in Amsterdam

Two operators (TNT and Heineken) have provided data from Amsterdam. Vehicle information and data availability are shown in Table 11. Because both vehicle dynamic data and state of charge data are provided, the COPERT 4v11 average speed functions are used to calculated NO_x, PM and CO_2 emissions, and well-to-wheel analysis can also be carried out.

Operator	vehicle_id	GWT (t)	Battery Capacity kWh	Average speed model can be used	W-T-W analysis	Days available	Total distance (km)
Heineken	1	12	120	Yes	Yes	53	1805
	2	12	120	Yes	Yes	178	9314
	3	12	120	Yes	Yes	51	1711
	4	12	120	Yes	Yes	80	4090
	5	12	120	Yes	Yes	63	3571
	6	12	120	Yes	Yes	35	2042
	Total					460	22534
TNT	1	3.5	62	Yes	Yes	277	24410
	2	3.5	62	Yes	Yes	130	9753
	3	3.5	62	Yes	Yes	303	21772
	4	3.5	62	Yes	Yes	120	6355
	5	3.5	62	Yes	Yes	260	22254
	6	3.5	62	Yes	Yes	275	24945
	7	3.5	62	Yes	Yes	248	13539
	Total					1613	123028

TOTAL						2073	145562

Table 11: Vehicle information and data availability for Amsterdam

There are in total 6 EFVs from Amsterdam Heineken and 7 EFVs from Amsterdam TNT. Detailed results from environmental impact analysis are shown in Table 12. Depending on the type of ICEVs that assume to be replaced, the total emission savings for Amsterdam demonstrators are:

- Amsterdam Heineken: NO_x savings from 154.4 kg and PM from 4.3 kg (assuming Euro III ICE trucks as the base line scenario) to NO_x savings of 29.3 kg and PM of 0.08 kg (assuming Euro VI ICE trucks as the base line scenario). Local GHG savings are around 21.2 to 19.3 tonnes CO_2e, while total GHG savings are around 8.0 to 6.2 tonnes. This represents a GHG reduction of around 35%.
- Amsterdam TNT: NO_x savings from 152.6 kg and PM from 9.4 kg (assuming Euro 3 ICE vehicles are replaced) to NO_x savings of 131.4 kg and PM of 0.23 kg (assuming Euro 6 ICE vehicles are replaced). Local GHG savings are around 44.1 to 42.0 tonnes CO_2e, while total GHG savings are around 20.9 to 18.9 tonnes. This represents a GHG reduction of more than 45%.
- In terms of the overall impact at the Amsterdam city level from FREVUE demonstration activities, NO_x savings are between 307.0 kg and 160.7 kg; PM savings are between 13.7 kg and 0.3 kg; total GHG savings are between 28.9 tonnes to 25.0 tonnes.

Operator	vehicle_id	Electricity consumption (kWh)	Comparing with ICEV equivalents …															
			Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
			NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
Heineken	1	2597	11452	324	1581	335	7099	62	1439	193	4211	63	1464	219	2037	6	1457	211
	2	13181	66791	1891	9134	2811	40624	352	8189	1867	24369	356	8337	2015	13124	36	8304	1981
	3	2016	10370	282	1441	474	6493	55	1316	349	3889	56	1338	371	1769	6	1328	361
	4	3800	26531	745	3654	1832	16395	142	3317	1494	9746	144	3375	1552	4797	15	3357	1534
	5	3624	24673	691	3385	1647	15100	130	3048	1309	9050	132	3101	1363	4704	13	3086	1348
	6	2263	14542	412	1990	905	8854	77	1786	700	5308	78	1818	732	2843	8	1810	725
	Total	27481	154360	4345	21185	8003	94566	818	19094	5913	56574	827	19434	6252	29274	85	19341	6159
TNT	1	6961	31087	1943	9020	5681	25166	1015	9020	5681	32886	47	8620	5281	26569	47	8620	5281
	2	3914	11544	677	3298	1421	9345	354	3298	1421	12329	16	3064	1187	9961	16	3064	1187
	3	9094	27781	1742	8066	3704	22489	910	8066	3704	29559	43	7787	3424	23881	43	7787	3424
	4	2985	7807	472	2247	816	6320	246	2247	816	8272	11	2112	680	6683	11	2112	680
	5	9142	25528	1463	7247	2862	20665	764	7247	2862	27633	35	6745	2360	22325	35	6745	2360
	6	10399	31581	1964	9153	4165	25566	1026	9153	4165	33488	48	8756	3768	27055	48	8756	3768
	7	5694	17286	1091	5024	2293	13994	570	5024	2293	18505	27	4888	2157	14951	27	4888	2157
	Total	48188	152614	9352	44056	20942	123545	4885	44056	20942	162673	225	41971	18858	131425	225	41971	18858
Total		75669	306974	13697	65241	28945	218111	5703	63150	26855	219247	1053	61405	25110	160699	310	61312	25017

Table 12: Direct environmental impact results - Amsterdam

Operator	vehicle_id	Veh count	Electricity consumption (kWh)	Comparing with ICEV equivalents …															
				Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
				NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
EMEL	RK	1		8238	531	2411		6669	277	2411		8720	13	2371		7045	13	2371	
CTT	RK ZE	4		2900	193	856		2348	101	856		3165	5	894		2557	5	894	
CTT	RK ZE	11	2883	10748	817	3157	2120	8671	427	3157	2120	12313	10	3157	2120	9945	9	3157	2120
Total		16	2883	21886	1541	6423	2120	17688	805	6423	2120	24198	29	6422	2120	19546	28	6422	2120

Table 13: Direct environmental impact results - Lisbon

2.4 Systemic and environmental impacts in Lisbon

Two operators, EMEL and CTT, have provided data from Lisbon. In total, data is available from 16 vehicles in Lisbon which have accumulated a distance of 18,689 km driven. Vehicle information and dynamic data availability are shown in Table 14.

There is one vehicle from EMEL which provides dynamic vehicle data, but not state of charge data. Therefore, for this EMEL vehicle, a well-to-wheel cannot be carried out. The data situation of the CTT vehicles are complex: 4 vehicles provide dynamic vehicle data but not state of charge data and 11 vehicles provide state of charge data (aggregated to daily level) but not dynamic vehicle data. The most suitable analysis options are carried out depending on the data situation, as shown in Table 14

Operator	Vehicle type	Vehicle count	W-T-W analysis	Average speed model can be used	GWT (t)	Battery Capacity kWh	Days available	Total distance (km)
EMEL	Renault Kangoo	1	No	Yes	2.2	22	91	6172
CTT	Renault Kangoo ZE Maxi	4	No	Yes	2.2	22	62	2082
CTT	Renault Kangoo ZE Maxi	11	Yes	No	2.2	22	225	10435
TOTAL		16					378	18689

Table 14: Vehicle information and data availability for Lisbon

Detailed environmental analysis results are presented in Table 13 above. For the EMEL Lisbon vehicle, the range of savings for NO_x is 8.2 – 7.0 kg and for PM is 0.5 – 0.01 kg depending on whether a Euro 3 or a Euro 6 ICEV is replaced by the EFV. The local GHG savings are around 2.4 tonnes CO_2e. Similarly, for the CTT Lisbon vehicles, the range of savings for NO_x is 13.7 – 12.5 kg and for PM is 0.8 – 0.01 kg, with total GHG savings around 2.1 tonnes CO_2e.

The overall impacts at the Lisbon city level from FREVUE demonstration activities include NO_x savings between 21.9 – 19.5 kg, PM savings between 1.5 – 0.03 kg, local GHG savings 6.4 tonnes CO_2e and total GHG savings 2.1 tonnes CO_2e. The estimation of total GHG savings is based on part of the fleets due to availability of the state of charge data.

2.5 Systemic and environmental impacts in London

There are two demonstrators in London, including a Clipper 10t electric truck and 43 UPS electric vehicles [14]. The total accumulative distance is 164,852 km from the London demonstrators. Vehicle information and data availability are presented in Table 15.

The Clipper vehicle does not have reliable state of charge readings therefore the well-to-wheel analysis cannot be carried out for this vehicle. However, dynamic data is available therefore the COPERT average speed models can be used for emission estimations.

[14] A number of FREVUE demonstrators, among them UPS, provided data for more vehicles than were co-funded.

The UPS vehicles provide state of charge data at the daily level, readings were reported both before a vehicle leaves the depot in the morning and after a vehicle returns in the afternoon. However there is no dynamic vehicle data, which means the COPERT aggregated emission factors are used to calculate environmental impacts.

Operator	vehicle_id	Vehicle count	W-T-W analysis	Average speed model can be used	GWT (t)	Battery Capacity kWh	Days available	Total distance (km)
Clipper	30F Smith	1	No	Yes	10	80	120	1932
UPS	EFA-S	43	Yes	No	5.5-7.5	51 - 62	5194	162920
TOTAL		44					5314	164852

Table 15: Vehicle information and data availability for London

For the reporting of GHG emissions, there are some significant differences between the COPERT aggregated GHG emission factors and the UK's Defra published emission factors[15], which would result in an underestimation of the GHG benefits. As the Defra's GHG factors are based on the average UK fleet composition, it should be more accurate at the local level compared to the COPERT factors (which are based on the EU average). Therefore Defra's factors are used to calculate GHG savings for UPS vehicles (still assuming a 50% load).

As shown in Table 16, for Clipper London, the NO_x reductions are between 8.6 kg (when replacing a Euro III ICEV) and 1.0 kg (when replacing a Euro VI ICEV) and PM reductions are between 233 grams and 5 grams. The local GHG emission savings are 1.2 tonnes CO_2e. For UPS London, the total NO_x savings are between 428.5 kg and 293.3 kg and the PM savings are between 9.2 and 0.08 kg depending on the type of ICEV used for comparison. Local GHG savings are 91.8 tonnes CO_2e and total GHG savings are 35%.

The overall impacts in London from FREVUE demonstration activities include NO_x savings between 428.5 kg and 29.3 kg, PM savings between 9.5 kg and 0.09kg, local GHG savings of 93 tonnes CO_2e and total GHG savings of 32 tonnes CO_2e.

2.6 Systemic and environmental impacts in Madrid

In Madrid, four EFVs were deployed from three operators. Vehicle information and data availability is summarised in Table 18. In total, these four vehicles have accumulated 43,688 km from 912 vehicle days. Apart from one vehicle which does not have state-of-charge data, the dynamic vehicle data and SoC data are all available.

Detailed analysis for each of the demonstrators in Madrid can be found in Table 18. Overall, because of FREVUE demonstration activities, there are NO_x savings between 61.9 kg and 55.0 kg; PM savings between 4.2 kg and 0.1 kg, local GHG savings around 19 tonnes CO_2e and total GHG savings of 12 - 13 tonnes CO_2e (67%), depending on the type of ICEVs assumed to be replaced.

[15] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016

Operator	vehicle_id	Veh count	Electricity consumption(kWh)	Comparing with ICEV equivalents …															
				Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
				NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
Clipper	30F	1		8577	233	1259		5697	49	1193		3432	49	1212		1028	5	1198	
UPS	EFA-S	43	103669	428481	9221	91772	32171	267190	1727	91772	32171	152005	1727	91772	32171	29326	81	91772	32171
TOTAL		44	103669	437058	9454	93031	32171	272886	1776	92965	32171	155437	1776	92984	32171	30353	86	92971	32171

Table 16: Direct environmental impact results - London

Operator	Veh count	Electricity consumption(kWh)	GHG from electricity (kgCO2e)	Comparing with ICEV equivalents …															
				Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
				NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
CP	1			4836	329	1435		3915	172	1435		5412	10	1571		4372	10	1571	
TNT	1	3234	1194	13170	900	3913	2719	10661	470	3913	2719	14700	26	4278	3084	11876	26	4278	3084
SEUR	1	5692	2101	28469	1935	8447	6346	23046	1011	8447	6346	31462	55	9100	6998	25418	55	9100	6998
CD	1	4418	1631	15416	1005	4525	2894	12480	525	4525	2894	16470	26	4542	2912	13307	26	4542	2912
TOTAL	4	13344	4926	61891	4170	18320	11959	50102	2178	18320	11959	68043	117	19491	12994	54973	117	19491	12994

Table 17: Direct environmental impact results - Madrid

Operator	Vehicle type	Vehicle count	W-T-W analysis	Average speed model can be used	GWT (t)	Battery Capacity kWh	Days available	Total distance (km)
CP	IVECO	1	No	Yes	3.3	21.2	100	3364
TNT	Renault Kangoo ZE	1	Yes	Yes	2.2	22	207	9113
SEUR	Renault Kangoo ZE	1	Yes	Yes	2.2	22	236	19834
CP	Mercedes Vito E-cell	1	Yes	Yes	2.2	22	369	11377
Total		4					912	43688

Table 18: Vehicle information and data availability for Madrid

2.7 Systemic and environmental impacts in Milan

In Milan, there is one electric light goods vehicle in operation as part of the FREVUE demonstration activity. As shown in Table 19, there is no dynamic vehicle data or state of charge data provided from this vehicle. Therefore well-to-wheel analysis cannot be carried out for Milan. Therefore the emission analysis is also based on the COPERT aggregated factors. The data is reported at the aggregate level and in total, this vehicle has accumulated 5,651 km from 85 days.

Operator	Vehicle type	Vehicle count	W-T-W analysis	Average speed model can be used	GWT (t)	Battery Capacity kWh	Days available	Total distance (km)
Milan	Nissan eNV200	1	No	No	1.5	24	85	5651

Table 19: Vehicle information and data availability for Milan

Detailed environmental analysis is shown in Table 21. As a result of this FREVUE demonstration, there are NO_x savings between 5.8 kg and 4.7 kg, PM savings between 442 grams and 5 grams and local GHG savings of 1.7 tonne CO_2e depending on the type of replaced ICE vehicle.

2.8 Systemic and environmental impacts in Oslo

Five electric light goods vehicle were deployed in Oslo as a part of the FREVUE demonstration. All vehicles provided state-of-charge data. However, due to a strict confidentiality agreement between SINTEF and Peugeot, this report does not have access to the dynamic vehicle data. Therefore the COPERT aggregated emission factors are used to calculate environmental impacts. Overall, these five vehicles have accumulated 180,415 km from 2,063 vehicle days.

Operator	Vehicle type	Vehicle count	W-T-W analysis	Average speed model can be used	GWT (t)	Battery Capacity kWh	Days available	Total distance (km)
BRING	Peugeot Partner	5	Yes	No	2.2	22.5	2063	180415

Table 20: Vehicle information and data availability for Oslo

Operator	Veh count	Electricity consumption(kWh)	GHG from electricity (kgCO2e)	Comparing with ICEV equivalents …															
				Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
				NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
Milan	1			5821	442	1709		4696	231	1709		6668	6	1709		5385	5	1709	
Oslo	5	39638	692	225950	13946	65350	64657	182912	7285	65350	64657	244079	351	64003	63310	197194	351	64003	63310

Table 21: Direct environmental impact results – Milan and Oslo

Operator	vehicle_id	Electricity consumption (kWh)	GHG from electricity (kgCO2e)	Comparing with ICEV equivalents …															
				Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
				NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
Operator 1	1	9124	4376	57256	1474	7592	3215	37519	296	7021	2645	22689	302	7188	2812	7404	30	7022	2646
	2	1341	643	8407	237	1146	503	5091	44	1024	381	3063	44	1042	399	1686	5	1038	395
	3	1951	936	13136	373	1801	865	8045	66	1585	649	4809	67	1612	676	2577	7	1604	668
	4	2177	1044	10962	312	1490	445	6599	57	1326	282	3968	58	1350	306	2256	6	1346	302
	5	2704	1297	14510	412	1998	701	8897	78	1803	506	5323	79	1835	538	2740	8	1827	530
	6	2333	1119	12860	355	1752	633	7977	66	1562	443	4762	67	1588	468	2282	7	1578	459
	7	2613	1254	14371	398	1959	705	8906	74	1745	491	5317	74	1773	520	2571	8	1763	509
	8	2361	1133	17910	514	2449	1316	10909	91	2148	1015	6522	91	2184	1052	3595	9	2176	1043
	Total	24605	11802	149411	4075	20186	8384	93943	772	18213	6411	56452	782	18573	6771	25110	79	18355	6553
Operator 3	1	17488	8388	58272	1511	8566	178	39332	327	8192	-197	23619	330	8309	-79	6049	33	8198	-190
Heinek	1	12430	5962	93800	2775	12321	6359	56900	472	10755	4793	34832	488	11135	5173	19644	49	10878	4916

Operat	vehicle	Electric	GHG	Comparing with ICEV equivalents ...															
en	2	6869	3295	54837	1622	7202	3907	33263	276	6286	2991	20364	286	6509	3214	11487	29	6359	3064
	3	6075	2914	28530	802	3969	1055	17830	155	3631	717	10599	157	3694	780	4875	16	3671	757
	4	25259	12116	96708	2683	13632	1517	61349	531	12584	468	36620	537	12794	678	15323	55	12696	580
	5	17302	8299	130614	3658	18339	10039	82247	716	16848	8548	49153	723	17135	8836	21593	74	17019	8719
	6	18497	8872	85516	2408	11912	3039	53358	465	10878	2006	31841	470	11067	2195	14821	48	11002	2130
	Total	86431	41458	490005	13948	67374	25916	304947	2616	60982	19524	183407	2661	62334	20876	87743	270	61624	20167
EMOSS	1	17955	8612	104295	2656	13873	5261	68589	535	12854	4242	41427	545	13141	4528	13056	55	12837	4225
	2	20284	9730	119880	3160	15886	6156	77565	615	14548	4819	46991	629	14917	5187	17145	63	14573	4843
	Total	38239	18342	224175	5816	29759	11417	146154	1150	27403	9061	88417	1174	28057	9716	30201	117	27410	9068
UPS	EFA-S	40635	19491	166058	3574	24114	4623	103550	669	24114	4623	58910	669	24114	4623	11365	32	24114	4623
TOTAL		207398	99481	1087921	28924	149999	50518	687925	5534	138903	39422	410806	5616	141388	41907	160468	532	139701	40221

Table 22: Direct environmental impact results – Rotterdam

	Veh count	Days available	Total distance (km)	Electricity consumption (kWh)	GHG from electricity (kgCO2e)	Comparing with ICEV equivalents ...															
						Euro III/ Euro 3				Euro IV - EGR / Euro 4				Euro V - EGR / Euro 5				Euro VI / Euro 6			
						NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)	NOx reduction (g)	PM reduction (g)	Local GHG reduction (kgCO2e)	Total GHG reduction (kgCO2e)
Project total	104	14424	762491	442602	202032	2147501	72174	400073	190371	1434321	23513	386821	177184	1128478	8948	387402	177612	628618	1430	385610	175833

Table 23: Direct environmental impact results – Project Total

Direct environmental impacts are shown in Table 21. Due to the FREVUE demonstration in Oslo, the total NO_x savings range between 226 kg (when replacing Euro III vehicles) and 197 kg (when replacing Euro VI vehicles), total PM savings are between 13.9 kg and 0.4 kg, local GHG emission savings are 64 tonnes CO_2e and the total GHG emission savings are close to 99%. The high total GHG savings are partially caused by low carbon emissions in Norway's electricity generation. As shown in Table 8, for one kWh generated in Norway, less than 20 grams CO_2e are emitted, which is around 30 times less than the GHG emissions of the UK grid. Another reason for the high total GHG savings in Norway is the energy consumption of their vehicles. Based on the analysis in D3.1 (SINTEF, 2017), the Oslo FREVUE demonstration vehicles travelled the longest distance per kWh consumed.

2.9 Systemic and environmental impacts in Rotterdam

Data has been received from 21 vehicles which are deployed by 5 operators in Rotterdam. Over the whole data collection period, all Rotterdam vehicles travelled in total 203,635 km over 3,599 vehicle days. Apart from UPS, all vehicles provided both dynamic vehicle data and state of charge data. Therefore both the well-to-wheel analysis and COPERT average speed emission models can be used. For UPS, due to the lack of dynamic vehicle data, COPERT aggregate factors are used to calculate emissions.

Operator	vehicle_id	Vehicle count	W-T-W analysis	Average speed model can be used	GWT (t)	Battery Capacity kWh	Days available	Total distance (km)
Operator 1	1	1	Yes	Yes	18	200	51	8687
	2	1	Yes	Yes	12	120	23	1135
	3	1	Yes	Yes	13.5	120	33	1583
	4	1	Yes	Yes	12	120	30	1426
	5	1	Yes	Yes	12	120	32	2145
	6	1	Yes	Yes	13.5	120	35	1703
	7	1	Yes	Yes	13.5	120	36	1890
	8	1	Yes	Yes	13.5	120	34	2074
	Total	8					274	20640
Operator 3	1	1	Yes	Yes	12	200	297	13902
Heineken	1	1	Yes	Yes	19	160	183	8864
	2	1	Yes	Yes	19	160	97	5179
	3	1	Yes	Yes	12	120	90	4723
	4	1	Yes	Yes	12	200	222	17382
	5	1	Yes	Yes	12	120	296	22606
	6	1	Yes	Yes	12	160	269	14033
	Total	6					1157	72786
EMOSS	1	1	Yes	Yes	16	200	221	16142
	2	1	Yes	Yes	16	160	261	17025
	Total	2					482	33167
UPS	EFA-S	4	Yes	No	7.5	62	1389	63140
TOTAL		21					3599	203635

Table 24: Vehicle information and data availability for Rotterdam

Detailed analysis for each of the operators is presented in Table 22. Due to the FREVUE demonstration in Rotterdam, , NO_x savings are between 1087.9 kg (when replacing Euro III vehicles) and 160.5 kg (when replacing Euro VI vehicles), total PM savings are between 28.9 kg and 0.5 kg=, local GHG emission savings are between 140 and 150 tonnes CO_2e and the total GHG emission savings are around 30%.

2.10 Project overall environmental impacts

Table 23 summarises the environmental impacts from all operators in the FREVUE project. Compared to Euro III/3 or Euro VI/6 equivalents, the overall NO_x savings are between 2147.5 kg and 628.6 kg, the overall PM savings are between 72.2 kg and 1.4 kg, and the overall local GHG savings are between 400 and 385 tonnes CO_2e respectively. The total GHG environmental loads, using well-to-wheel analysis, are between 190 and 176 tonnes CO_2e, which represents a saving of about 45%.

It should be noted that the direct environmental impact results are significantly affected by the type of ICEVs that are replaced by EFVs. When comparing environmental benefits of Euro III/3 and Euro VI/6 with EFVs, there are significant differences between heavy goods vehicles and light goods vehicles, particularly in the case of NO_x savings.

For example, in Rotterdam the majority of FREVUE vehicles are electric HGVs. Here the NO_x savings of replacing a Euro VI conventional heavy goods vehicle are around 15% of the NO_x benefits of replacing a Euro III conventional heavy goods vehicles. This difference of around 85% confirms the tests reviewed in section 2.1.1.3 of the effectiveness of Euro VI standards for HGVs.

However, in Madrid where all the electric vehicles are LGVs, the difference in NO_x savings between Euro 3 and Euro 6 vehicles compared to EFVs are only around 12%, which is in line with the reviews in section 2.1.1.3 regarding the ineffectiveness of emission control from some of the Euro 6 LGVs. As new test procedures and new Euro 6c standards are planned to be introduced, the emission performance for newer vehicles might be greatly improved in future.

Due to the use of diesel particulate filters, significantly less PM emissions can be observed for both Euro VI (reduction up to 99%) and Euro 6 (reduction up to 97%) ICEVs. These filters have led to less PM benefits when comparing Euro III/3 and Euro VI/6 with EFVs. However, as there are no safe limits for fine particles ($PM_{2.5}$) any reductions in PM are still highly beneficial to human health.

Overall the project achieved a reduction of 45% total GHG emissions, which is in line with other similar studies. However, significant variations exist between different operators. For example, in Oslo where the electricity has very low carbon emissions, the total environmental GHG reduction is over 90%. However, for some operators in Rotterdam, the total environmental GHG reduction is very small. There are a few reasons behind this variation, including:

- A high-carbon power. For example, UK emits over 50 times more CO_2 equivalents per kWh generated compared to Norway.
- The assumption of 50% load for emission calculation may underestimate GHG emission savings. This is applicable for operators where vehicles undertake both delivery and pick-up in a round-trip which (resulting in a higher average load factor).
- Conventional ICE vehicles are much more efficient at higher speeds than lower speeds. Therefore if an EFV is mainly used for high speed trips, its GHG saving benefits are smaller. This was evident in Rotterdam where a number of vehicles have high speed trips.

- Road gradients also have significant impact on energy consumption. In this analysis, it is assumed that the roads are flat.
- The COPERT speed dependent or aggregated factors are based on average EU fleets, which may not reflect the specific vehicle situations in each operator.

As the power sector is decarbonised, the total GHG emission benefits would improve when using EFVs, assuming bio-fuel blending with diesel does not increase substantially over current levels

3 Potential Impacts at Different EFV Penetration Levels

3.1 Introduction

Due to the limited scale of EFV deployment undertaken in the FREVUE project, it is difficult to assess the impact of a mass uptake of EFVs. This is of interest to policy makers because if the benefits are significant and quantifiable, this could be used to facilitate policy on encouraging a higher uptake of EFVs.

In order to estimate the impacts at different EFV penetration scales, the existing city traffic composition, traffic flow/network condition, freight demand and freight traffic distribution are required. Many types of traffic models can potentially provide these types of data, including strategic transport models, microsimulation models and local area models. However, due to the requirements of spatial coverage (city centres and surrounding areas), the strategic transport models (also called macroscopic models) are the most suitable. Therefore, Imperial has approached each of the demonstration cities, interviewed the relevant transport departments and reviewed the models they have. In the end we obtained three strategic models from Amsterdam, London and Rotterdam. For other cities we established that no suitable model exists. Further examinations for Rotterdam showed that only the base-year model was available and the forecast year models were not delivered in time. Therefore, Amsterdam and London are the cities where this modelling analysis can be carried out.

3.2 London

3.2.1 Model description

The London traffic model used in this study is provided by Transport for London. The model is called London Highway Assignment Model (LoHAM) and the version used is LoHAM P3.3 R073. LoHAM was developed based on SATURN[16] (Simulation and Assignment of Traffic to Urban Road Networks), which is a widely-used software for transport simulation and assignment in the United Kingdom. SATURN version used in this study is 11.3.12U.

The LoHAM P3 model is developed by TfL to simulate traffic flows and congestion in Greater London extending beyond the M25 boundary. As shown in Figure 21, the LoHAM network covers the whole of Great Britain, but is very detailed in the Greater London area with reducing detail as distance from London increases.

[16] https://saturnsoftware2.co.uk/

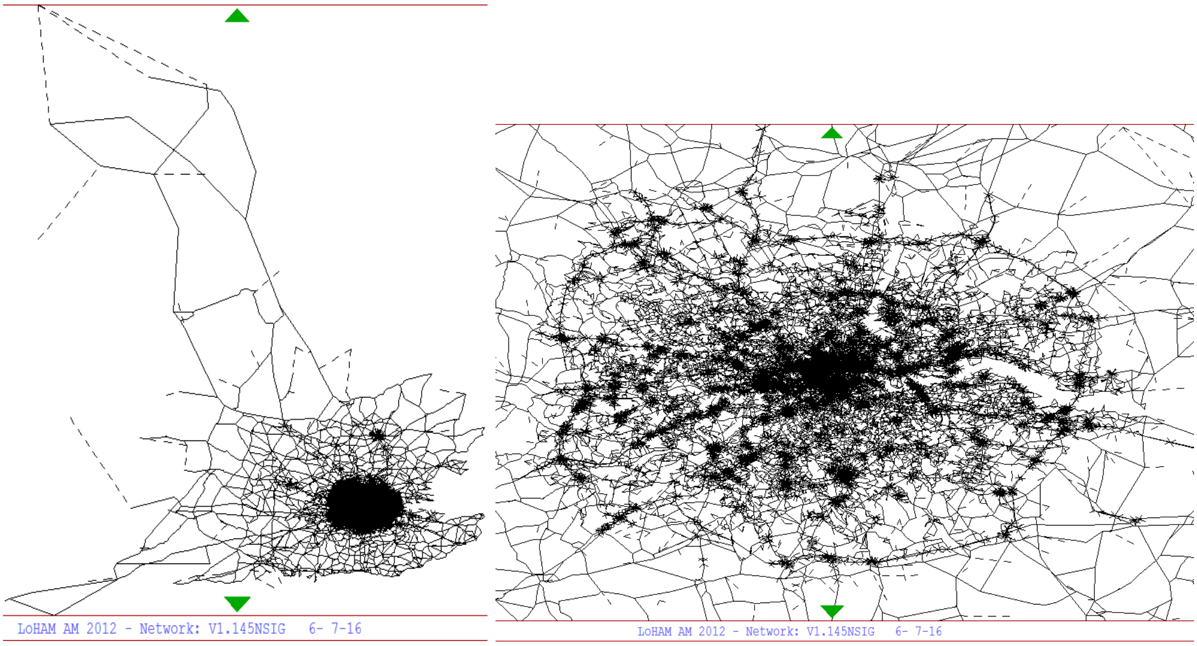


Figure 21: LoHAM Traffic Model – Network coverage
(left: whole network; right: Greater London area)

Due to the level of network detail, the LoHAM model is extremely complex, as shown in Table 25. There are over 5000 zones where the traffic demands are loaded to the network, over 30,000 junctions and 70,000 links are represented in this model.

Model structure	Numbers
Zones	5,194
Nodes (junctions)	30,441
Links	71,829

Table 25: LoHAM Network Statistics

There are three modelled time periods, including

- AM Peak Hour: 08:00 – 09:00
- Inter Peak average hour over period 10:00 – 16:00
- PM Peak Hour: 17:00 – 18:00

Five user classes are represented in the model, which include:

- Car in work
- Car not in work
- London taxi
- Light goods vehicle (LGV)
- Other goods vehicle (OGV[17])

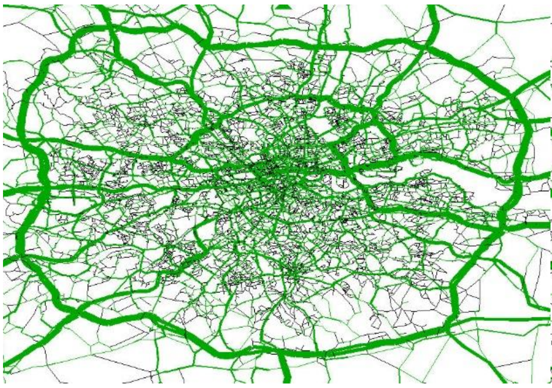
The definition of OGV includes 2 or more axles rigid and 3 or more axles articulated heavy goods vehicles with more than 3.5t gross vehicle weight.

The model is calibrated to a 2012 base year, with forecast years of 2021 and 2031. A detailed model development and calibration report is available in TfL (2016a).

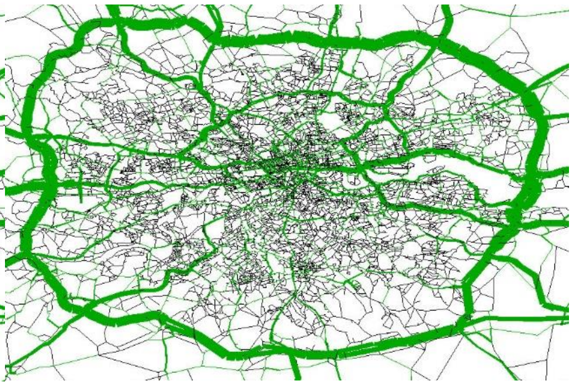
[17] The definition of OGV can be found in DMRB Volume 7, Section 2, Part 1: http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol7/section2/hd2406.pdf

3.2.2 Freight traffic

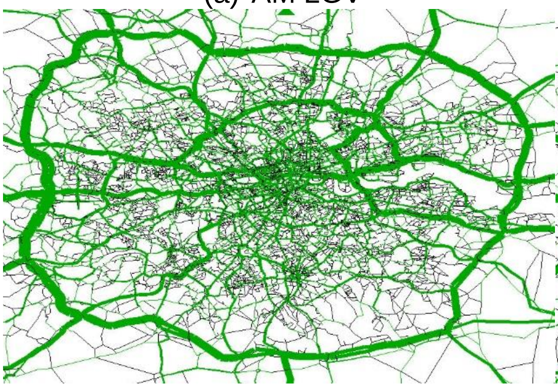
By using traffic models, it is possible to understand the spatial distribution of goods traffic flows. Figure 22 shows the LGV and OGV flow distribution within the Greater London area by three peak periods in year 2021. Black lines are links which represent road networks. Green lines represent LGV or OGV flows and the width of the bandwidth is proportional to the level of traffic. By comparing LGV traffic flows with OGV traffic flows, it can be seen that LGV traffic penetrates deeply into both major roads (such as motorways and A roads) and minor roads. Hence they distribute widely into the road network. The OGV traffic flows, however, seem to concentrate around major roads, for example the M25, M4, M1, M11, A13, A2, A3 and the north circular road. The difference of spatial distribution from LGV and OGV flows reflect the preference of route choices from different type of vehicle users.



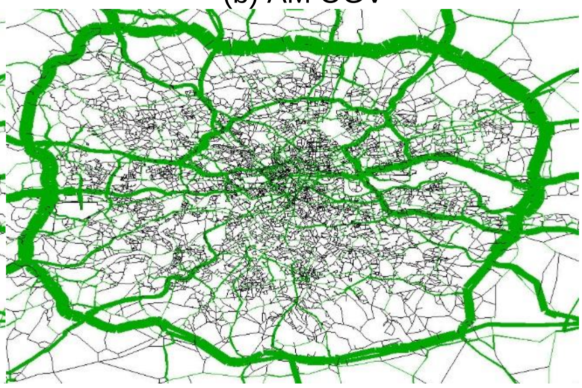
(a) AM LGV



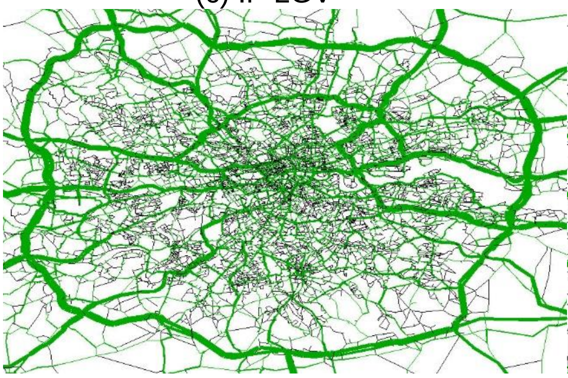
(b) AM OGV



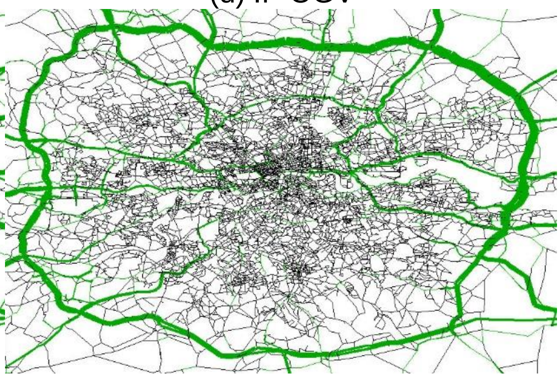
(c) IP LGV



(d) IP OGV



(e) PM LGV



(f) PM OGV

Figure 22: Goods traffic flow distribution by time periods and vehicle class – 2021 London

When comparing LGV and OGV flows by time periods, it can be clearly seen from Table 26 that there are similar levels of traffic between AM and inter-peak (IP) periods. The PM period, however, seems to have less traffic and this is especially the case for the OGV flows. The observations of flow differences across time periods and the route choice differences between LGV and OGV traffic are also applicable to the 2031 model.

Year	Vehicle type	vehicle.km		
		AM peak	IP peak	PM peak
2021	LGV	1180595	1233182	1088978
	OGV	491798	543650	269849
2031	LGV	1300625	1369385	1192541
	OGV	479145	540739	261999

Table 26: Vehicle kilometres by time periods and vehicle classes in London – LoHAM

3.2.3 Trip length distributions

Next, we look at trip length distributions for both LGV and OGV across different time periods. The trip length distribution is a distribution summary of the distances which each vehicle travels from origin to their destination. When exploring the potential environmental benefits of electrifying fleets for urban goods delivery, it is important to recognise that for some type of trips, such as long range, inter-city trips, it is impossible to replace conventional HGVs with EFVs in the short term due to range/battery limitations. In the long term, as technology develops, it might be possible to electrify the whole fleet.

The zones used in calculation for trip length distribution is shown in Figure 23. In total, 4735 out of 5194 zones are selected. Only LGV or HGV traffic going in or coming out of the highlighted area (essentially all the zones within the M25) are included in the distribution.

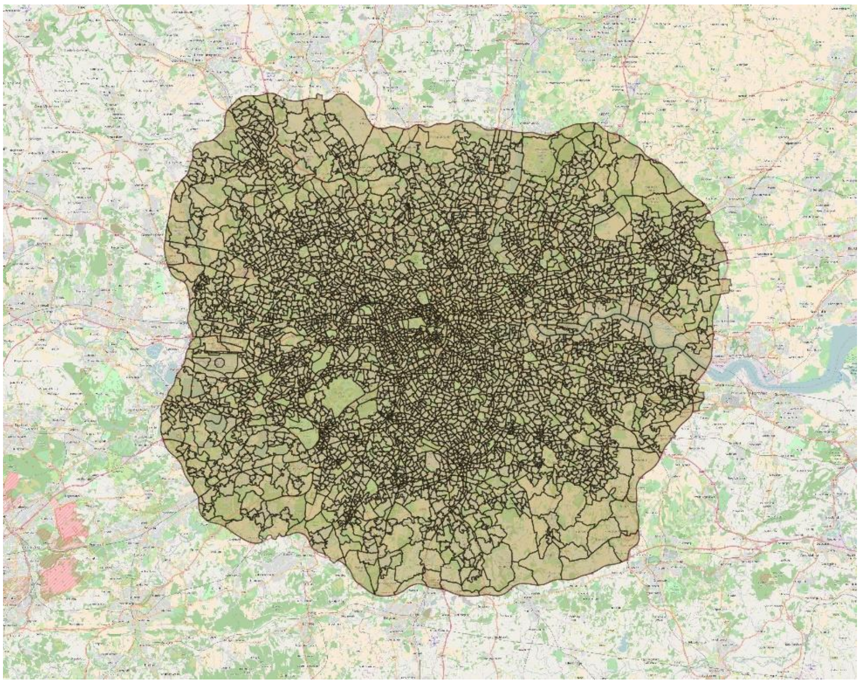


Figure 23: Zones included for trip length distribution calculation - LoHAM

The following figures present trip length distributions for both LGV and OGV in year 2021.

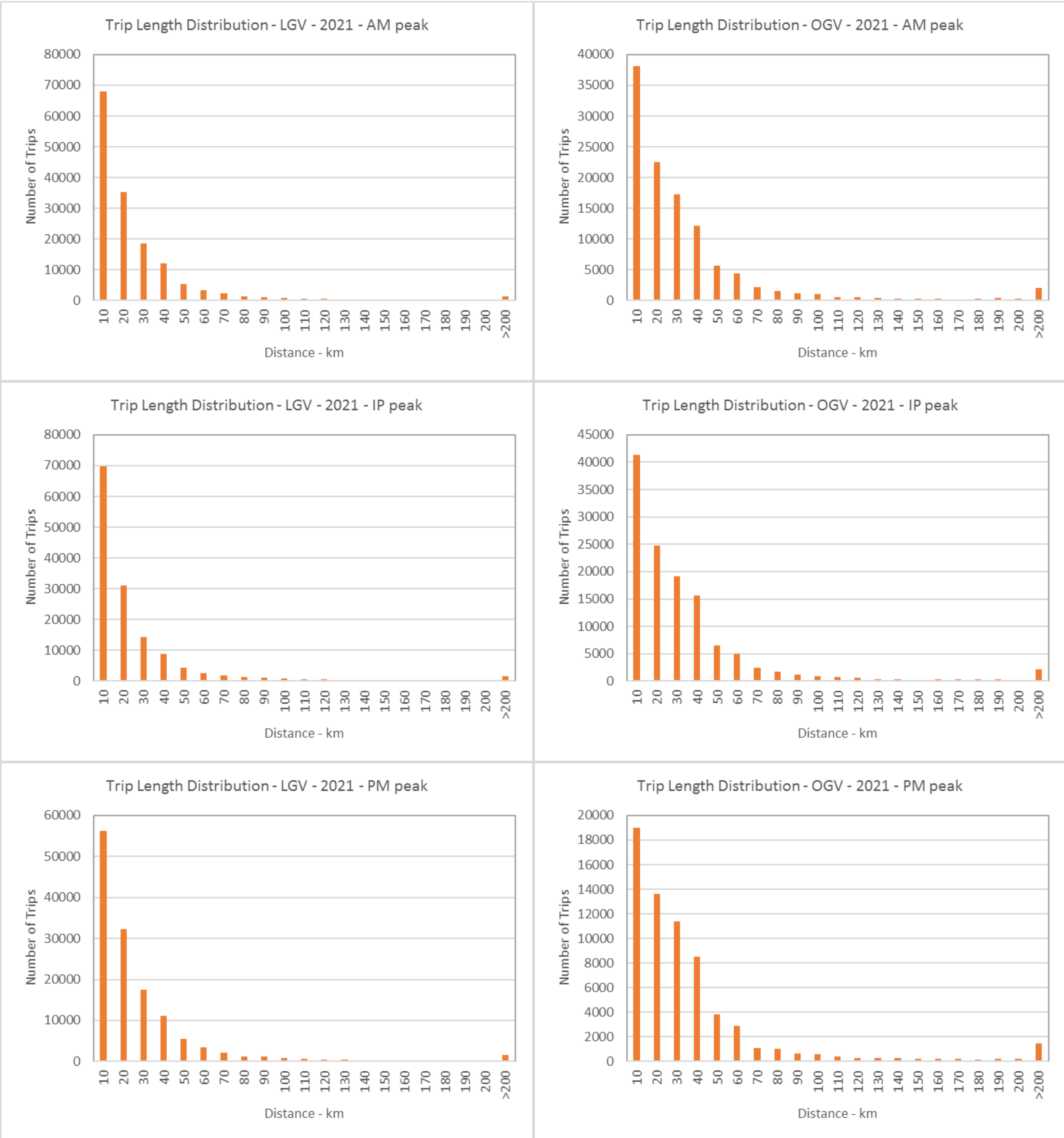


Figure 24: Trip length distributions for LGV and OGV traffic for AM, IP and PM periods – LoHAM (2021)

The trip length distributions from year 2031 are also produced but are not listed here due to the similarities of the shape of the distributions. It can be concluded that for LGV traffic, over 90% of the trips are under 50km, 95% of the trips are under 100km and around 99% of the trips are under 200km. For OGV traffic, over 85% of the trips are under 50km, 95% of the trips are under100km and 98% of the trips are under 200km. For both LGV and OGV traffic, the longer trips (over 200km) only represent a small fraction of the total goods traffic.

In the FREVUE project, some of the electric trucks deployed have an estimated range of 200km. Therefore, for this analysis, it is assumed that there is no restriction from the perspective of trip length and all LGV and OGV traffic can be electrified in London. However, other factors, such as fleet composition and gross vehicle weight, may become a constraint on whether it is feasible to electrify existing fleets. This is discussed in the following section.

3.2.4 Future fleet composition forecast

As demonstrated in Chapter 3, fleet composition would have a significant impact on environmental benefits2. Furthermore, the LoHAM model does not distinguish between rigid and articulated HGV traffic in its OGV user class. Therefore, it is important to have reliable estimates for future fleet compositions.

For this analysis, the latest "base 2013 fleet composition projections" which is published by Defra[18] is used. The percentage of vehicles using different Euro emission standards by year 2021 and 2031 is listed in Table 27. Based on Defra's projection, more than 70% of LGVs deployed in the London area will be of Euro 6 standard by 2021, and the percentage is even higher for HGVs. By 2031, all vehicles are Euro 6/VI compliant.

Euro Standard	LGV		HGV - rigid		HGV - Artic	
	2021	2031	2021	2031	2021	2031
Pre-Euro I	0%	0%	0%	0%	0%	0%
Euro I	0%	0%	0%	0%	0%	0%
Euro II	0%	0%	0%	0%	0%	0%
Euro III	0%	0%	0%	0%	0%	0%
Euro IV	6%	0%	3%	0%	0%	0%
Euro V	23%	0%	20%	0%	6%	0%
Euro VI	71%	100%	77%	100%	94%	100%

Table 27: London fleet composition forecast for LGV and HGV – 2021 and 2031

Projections by weight for the HGV fleets are shown in Table 28 as calculated by Defra. The percentage of HGV fleet by weight is the same for year 2021 and 2031. According to the forecast, around 53% of rigid HGVs in both 2021 and 2031 in London will weigh less than 20t. However, for articulated HGV, only 2% of the fleet will weigh less than 20t.

HGV - rigid			HGV - artic		
GVW	2021	2031	GVW	2021	2031
3.5-7.5 t	33%	33%			
7.5-12 t	6%	6%			
12-14 t	2%	2%			
14-20 t	12%	12%	14-20 t	2%	2%
20-26 t	16%	16%	20-28 t	3%	3%
26-28 t	9%	9%	28-34 t	2%	2%
28-32 t	18%	18%	34-40 t	16%	16%
>32 t	4%	4%	40-50 t	76%	76%

[18] http://naei.defra.gov.uk/resources/rtp_fleet_projection_Base2013_v3.0_final.xlsx

Table 28: HGV fleet composition by Gross Vehicle Weight in London – 2021 and 2031

In terms of percentage share of vehicle kilometres in London, articulated HGVs only occupy a small percentage of total OGV traffic, as shown in Table 29. However, the share is very different for motorway traffic, as articulated HGVs represent more than 55% of total HGV mileage.

	London - Central		London - Inner		London - Outer		Motorways	
	2021	2031	2021	2031	2021	2031	2021	2031
HGV - Rigid	89.2%	89.2%	85.2%	85.2%	84.9%	84.6%	43.6%	44.4%
HGV - Artic	10.8%	10.8%	14.8%	14.8%	15.1%	15.4%	56.4%	55.6%

Table 29: Forecasted OGV vehicle kilometres split of HGV in London (source: NAEI)

Although articulated HGVs with large gross vehicle weight might be difficult to electrify based on current technologies, this is likely to change in the future with technology advances and innovative charging solutions. For example, BMW and Scherm have trialled a 40t electric truck on public roads[19]. Therefore, to compare future environmental benefits, all types of HGVs are considered in the calculation.

Because the LoHAM network coding file does not specifically define whether a link belongs to London central, London inner or London outer, HGV rigid and artic traffic flow share from London inner is used for all London HGV traffic (non-motorway). For motorway HGV traffic, the HGV rigid and artic flow share for motorway is used (see Table 29).

3.2.5 Deriving daily traffic flows from the LoHAM model

The LoHAM model provides traffic assignment results for three time periods, as discussed in section 3.2.1. However, for environmental impact analysis, daily traffic flows are required. |Therefore there is a conversion process to expand the LoHAM peak period traffic flows to annual average daily traffic (AADT).

There are many ways to do this conversion, the traditional way is to use the approach set out in COBA[20]. Typically, traffic count sites need to be selected based on the study area, then hourly traffic counts from the chosen sites are compared to modelled hourly flows. A set of factors can then be derived from here to convert the modelled peak hour flows to peak periods flow and then to 24hr annual average daily traffic (AADT).

LoHAM does not provide standard AADT factors. To obtain these factors, it requires access to an extensive amount of hourly traffic count data from many traffic count sites around the Greater London Area. However, this type of data is not available to Imperial College. It was therefore decided to use the AADT expansion factors derived in another Highways England project. This project's study area is around the M25 (between junction 1a and junction 3) and the A2 (from M25/A2 junction to A2/ Bean lane). The study area is much smaller than our interest area which is the Greater London Area. However, the types of roads included in the study are similar to ours and these factors should be a reasonable approximation. The factors used are shown in Table 30.

		LGV (UC4)	OGV (UC5)

[19] https://www.cnet.com/roadshow/news/bmw-puts-a-40-ton-electric-truck-on-the-road/

[20] http://webarchive.nationalarchives.gov.uk/20100304070241/http://www.dft.gov.uk/pgr/economics/software/coba11usermanual/part4trafinputtocobarevis315.pdf

Peak hour to peak period factors	AM Peak Hour (08:00-09:00) to AM Peak Period (07:00-10:00) Factor	2.6046	3.0385
	Average Inter Peak Hour (10:00-16:00) to Inter Peak Period (10:00-16:00) Factor	6.0000	6.0000
	PM Peak Hour (17:00-18:00) to PM Peak Period (16:00-19:00) Factor	2.7822	3.0875
	Inter Peak Period (10:00-16:00) to 12-hour Off-Peak Period (19:00-7:00) factors	0.6959	0.4747
Weekday to annual average day (24hr) factors	Weekday AM Peak Period (07:00-10:00) to Annual Average Day AM Peak Period (07:00-10:00) Factors	0.8299	0.7579
	Weekday IP Period (10:00-16:00) to Annual Average Day IP Period (10:00-16:00) Factors	1.0288	0.7680
	Weekday PM Peak Period (16:00-19:00) to Annual Average Weekday PM Peak Period (16:00-19:00) Factors	0.9046	0.7571
	Weekday 12-hour Off-Peak Period (19:00-07:00) to Annual Average Day 12-hour Off-Peak Period (19:00-07:00) Factors	0.8722	0.7838

Table 30: AADT expansion factors for LoHAM

3.2.6 Environmental impacts of EFVs at different market penetration levels

Having obtained AADT figures, environmental impacts can now be calculated. The calculation is based on a spreadsheet-based tool called "Emission Factors Toolkit" or EFT, which is published by Defra[21] to assist local authorities in carrying out review and assessment of local air quality (Defra, 2016) in the United Kingdom. The latest version is v7.0 which is also the version used in this analysis. The EFT allows users to calculate road vehicle pollutant emission rates for NO_x, PM, and CO_2 for a specified year, road type, vehicle speed and vehicle fleet composition.

In this latest version, COPERT 4v11 speed functions were implemented to calculate NO_x and PM related emissions. The calculations of annual link-based emissions are carried out for AM, IP, PM and off-peak periods separately to take account the speed differences among different time periods. Although EFT 7.0 is capable of calculating PM from tyre and brake wear and road abrasion emission sources, this analysis, only considered exhaust emissions. Refer to the user manual or further information on the methodology, datasets and assumptions used in EFT (Defra, 2016).

The analysis of environmental impacts is made separately based on three market penetration scenarios:

- low penetration: only 10% of the total freight vehicles are electrified
- medium penetration: 50% of the total freight vehicles are electrified
- high penetration: 100% of the total freight vehicles are electrified

For the baseline scenario, it is assumed that all vehicles are conventional ICE vehicles based on the fleet composition forecasts. Results are then presented by comparing emission savings from different EFV penetration levels against the baseline scenario at different forecast years (i.e. 2021 and 2031 for London).

Based on the above discussions, the calculation process for the environmental impacts using LoHAM traffic model is summarised in the Figure 25 below. Results from this analysis are shown in Table 31, which are calculated based on all the links including and within the M25 area (Figure 23).

[21] https://laqm.defra.gov.uk/review-and-assessment/tools/emissions-factors-toolkit.html

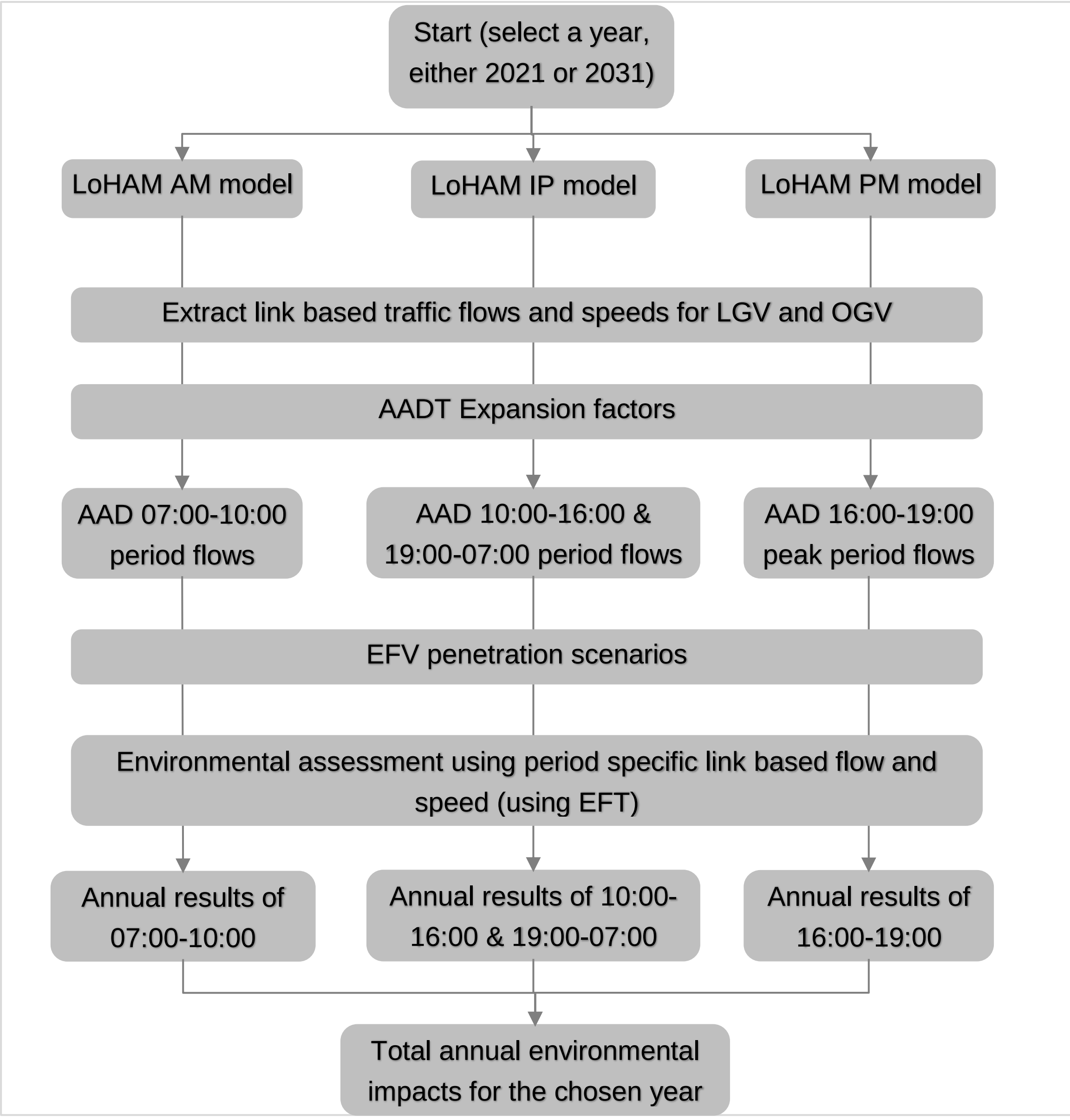


Figure 25: Environmental impact analysis using London LoHAM model – flow chat

Emission reductions	Penetration levels		
2021	Low	Medium	High
CO_2 (tonnes)	284,242	1,421,212	2,842,424
NO_x (kg)	402,138	2,010,688	4,021,376
PM_{10} exhaust (kg)	3,836	19,181	38,361
2031	Low	Medium	High
CO_2 (tonnes)	289,179	1,445,896	2,891,792
NO_x (kg)	248,930	1,244,650	2,489,299
PM_{10} exhaust (kg)	1,686	8,432	16,863

Table 31: Environmental impacts in London in 2021 and 2031 at different EFV penetration levels

In year 2021, for the Greater London area, the maximum benefits from electrifying goods vehicle fleets are CO_2 savings of 2.8 million tonnes per year, NO_x savings of 4,021 tonnes per year and exhaust PM_{10} savings of 38 tonnes per year, based on the assumption that all conventional vehicles are converted into electric vehicles. The benefits for medium and low penetration levels are smaller but significant amounts of emission savings can still be expected.

In year 2031, due to a wider deployment of the Euro VI/6 vehicles with better emission control technologies, the NO_x and PM_{10} reductions are smaller compared to 2021 results, with 2,489 tonnes and 16.8 tonnes savings per year respectively in the Greater London area for the high penetration scenario. The CO_2 emission savings, however, increase to 2.9 million tonnes per year due to higher vehicle mileages. Similar patterns can be observed for the low and medium penetration scenarios.

3.3 Amsterdam

3.3.1 Model description

The Amsterdam traffic model (VMA) used in this analysis is owned and provided by the City of Amsterdam. Similar to LoHAM, the VMA is structurally alike to a traditional four-stage traffic model. The VMA is developed based on a Dutch software called OmniTRANS[22]. Version 6.1.6 is used in this analysis.

The base year of the VMA is 2010 and the forecast years are 2015, 2020, 2025 and 2030. It has eight user classes, including:

- car driver,
- car passenger,
- OV users, Train,
- BTM (bus/tram/metro),
- cycle, walking, and
- freight.

Three time periods are modelled, including:

- Morning peak periods (07:00 – 09:00)
- Evening peak periods (16:00 – 18:00)
- Rest of the day (09:00 – 16:00 & 18:00 – 07:00)

Unlike the LoHAM model, AADT factors are not required to calculate link based daily traffic flows. For the VMA model, the daily traffic flows can be obtained by simply adding the flows from all three periods.

Similar to the LoHAM model, the VMA covers a large area; however the detail of the network reduces as the distance increases from Amsterdam city centre. In Figure 26, the figure on the left is the whole VMA network in year 2020. As can be seen, it covers part of Germany, Belgium and France. The plot on the right in Figure 26 shows an extremely detailed Amsterdam area. The different line colours represent different types of links.

[22] http://www.omnitrans-international.com/en

Figure 26: Modelled area in the VMA (2020)

Statistics of the VMA network are provided in Table 32 for year 2020. For other forecast years, the scale of the network is very similar.

Model structure	Numbers
Zones	5,222
Nodes (junctions)	74,148
Links	101,071
Transit lines	1,281
Stops	7,311

Table 32: VMA network statistics (2020)

For long term forecasts (2025 and 2030), the VMA estimates future flow uncertainties based on different “prosperity scenarios”. These are defined by the Netherlands Bureau for Economic Policy Analysis (CPB) to consider future development of the Netherlands. Various factors such as economic growth at home and abroad, employment, income development, population growth and spatial development are considered. Two of these scenarios are considered in the VMA 2025 and 2030 model, including Global Economy (GE), which is the highest growth scenario, and the Regional Communities (RC) which is the lowest growth scenario.

Apart from these two growth scenarios, all forecast years (2015, 2020, 2025 and 2030) make demand and traffic flow forecasts based on an Amsterdam Realistic scenario (AR).This is a scenario based on the socio-economic trends observed in recent years and the most likely planned development as expected by the Amsterdam’s planning department (DRO).

As it is available for all forecast models, the results from Amsterdam Realistic scenario (AR) should be used for this analysis. Year 2020 and 2030 are analysed, with a similar methodology to the London analysis.

There are eight boroughs in Amsterdam, as shown in Figure 27. All these eight boroughs are included in this analysis. Together, there are 21,633 links in these boroughs in the VMA. The Amsterdam municipality area covers around 220 km^2 with a population of 850,000.

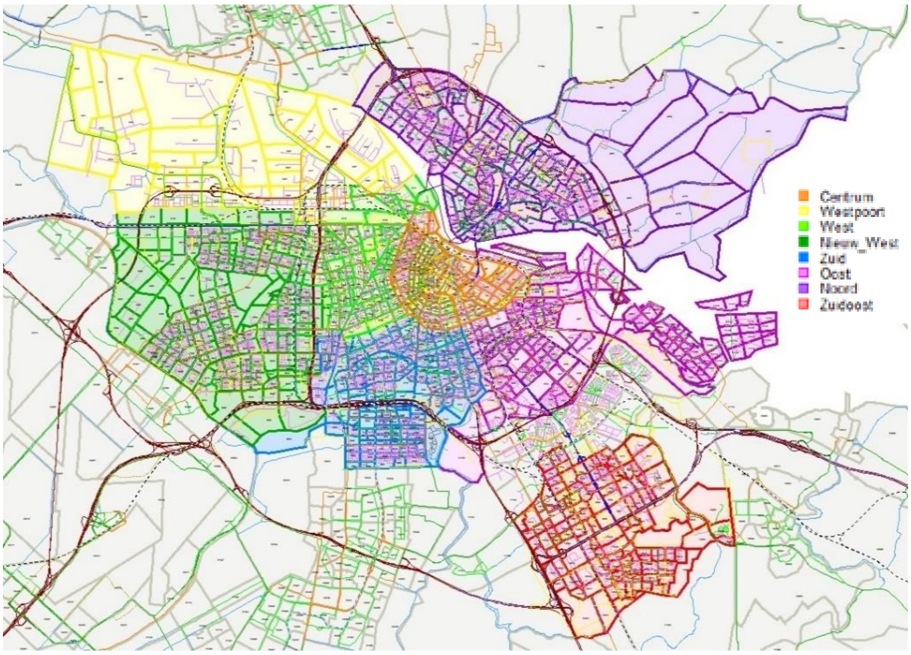


Figure 27: Overview of Amsterdam boroughs (analysis area)

3.3.2 Freight traffic

The spatial distribution of freight traffic flows in and around the Amsterdam area is shown in Figure 28. This represents the total daily flow in year 2020 by adding the modelled freight traffic from all three periods. Black lines are links which represent road networks. Red lines represent freight traffic and the width is proportional to the level of traffic. Similar to what has been observed for the HGV flows in the LoHAM model, freight traffic in the VMA also shows strong concentration around major roads, including the A1, A4, A5, A8, and A10. Less freight traffic is moves through central Amsterdam. Similar observations can be found on the 2030 VMA model.

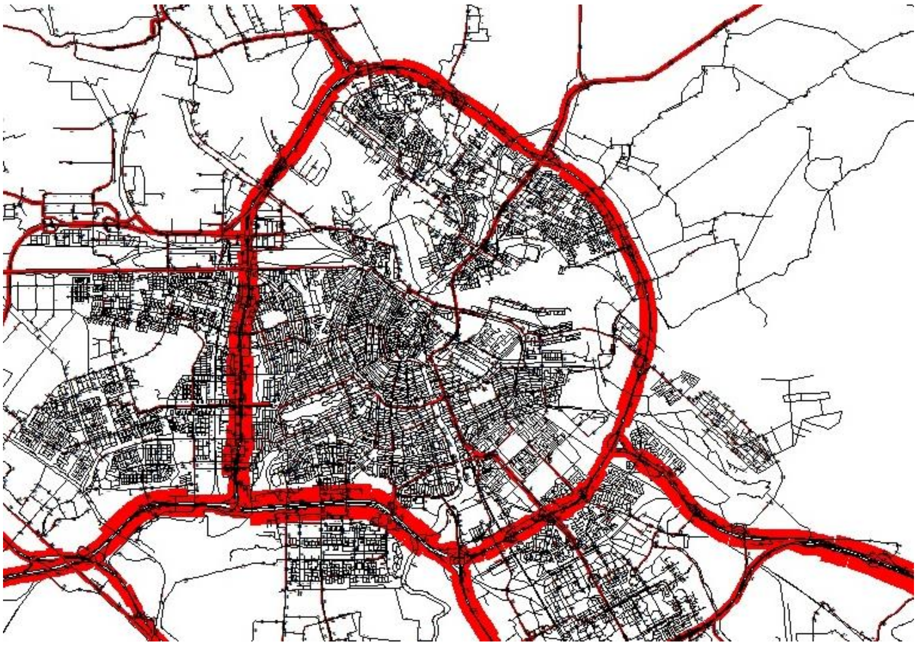


Figure 28: Freight traffic distribution (whole day)– VMA (2020)

Daily total vehicle kilometres are shown in Table 33. Each day, it is predicted that there will be more than 1.1 million vehicle-kilometres freight traffic inside the Amsterdam area in 2020.

By 2030, the amount of freight traffic is predicted to increase to nearly 1.2 million vehicle-kilometres every day in Amsterdam. Morning peak is the busiest period during the day for freight traffic, followed by the evening peak periods.

Year	per hour			per periods			Total
	AM	Rest of day	PM	AM	Rest of day	PM	
2020	89649	43242	64054	179297	864847	128109	1172253
2030	91866	44137	65931	183732	882732	131862	1198326

Table 33: Vehicle kilometres for Amsterdam area in 2020 and 2030

3.3.3 Trip length distributions

Trip length distributions are produced for the freight traffic from the VMA (network wide plots, not just the study area). As shown in Figure 29, the shape of the trip length distributions across three periods are very similar. The majority of the freight trip distances are within 100 km, with very few trips over 200 km. Therefore all trips are included in the impact analysis for testing different EFV market penetration levels.

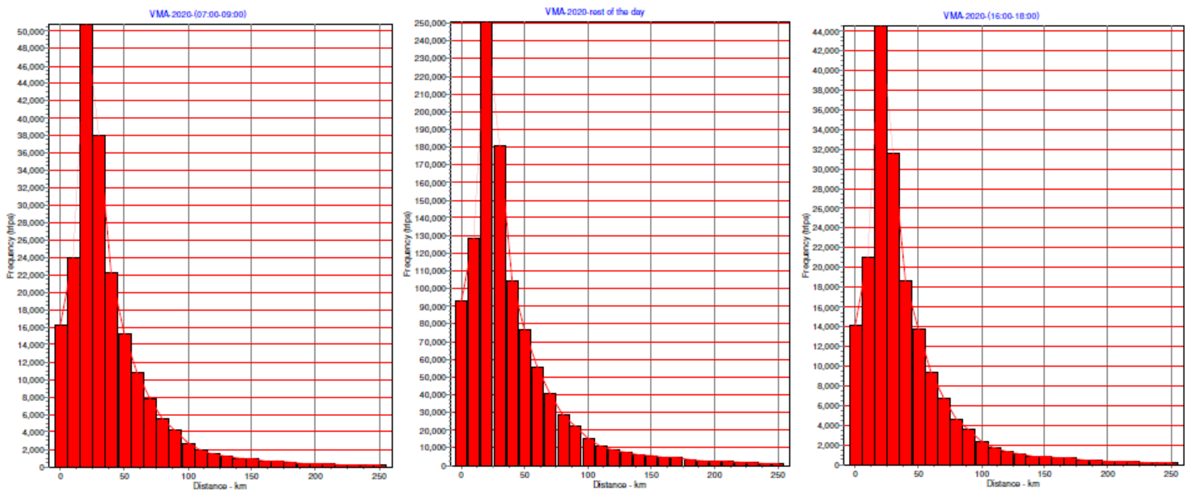


Figure 29: Trip length distributions for morning peak, rest of the day and evening peak periods in year 2020 (VMA)

3.3.4 Fleet composition forecast

Detailed Amsterdam fleet composition forecasts are not available to Imperial. However, a report published by TNO (Ligterink, 2015) brings some interesting insights into past fleet composition and fleet age distribution in the Netherlands.

It is concluded that for the urban heavy-duty fleet, smaller trucks (3.5t to 10t) represent 12% of the fleet, medium sized trucks (10t to 20t) form 35% of the fleet and remaining heavy goods vehicles (20t and above) comprise 53% of the total.

When comparing the goods transport by gross vehicle weight, significant differences can be observed between the UK and the Netherlands, as shown in Table 34. There seems to be a much higher proportion of over 40t vehicles in the Netherlands than in the UK. Unfortunately the vehicle kilometres data is not available so it is not possible to directly compare the traffic mileage from goods vehicles between the two countries.

However, it should be noted that the data is presented at the country level. Large variations are expected at the city level due to road characteristics, local policy for goods vehicles and access restrictions.

	0 - 6 tonnes		6.1 - 10.0 tonnes		10.1 - 20.0 tonnes		20.1 - 30.0 tonnes		30.1 - 40.0 tonnes		> 40.0 tonnes		Total
	Million tkm	% of total	Million tkm	% of total	Million tkm	% of total	Million tkm	% of total	Million tkm	% of total	Million tkm	% of total	Million tkm
EU-28 (¹)	2 135	0.1	8 292	0.5	165 359	9.4	96 122	5.4	855 553	48.5	636 130	36.1	1 763 827
Belgium	993	3.1	114	0.4	23 264	73.3	6 703	21.1	655	2.1	:c	-	31 729
Bulgaria	:c	-	267	0.8	965	3.0	2 150	6.7	19 716	61.0	9 192	28.5	32 297
Czech Republic	146	0.3	948	1.7	3 063	5.4	3 401	5.9	8 128	14.2	41 513	72.6	57 200
Denmark	:	-	26	0.2	465	3.0	773	5.0	3 343	21.6	10 893	70.3	15 500
Germany (²)	11	0.0	419	0.1	9 227	3.0	15 993	5.2	242 670	78.2	41 822	13.5	310 142
Estonia	:	-	2	0.0	72	1.1	165	2.6	19	0.3	6 005	95.9	6 263
Ireland	34	0.3	114	1.2	221	2.2	513	5.2	1 510	15.3	7 508	75.8	9 900
Greece	:	-	207	1.0	1 265	6.4	1 492	7.5	15 576	78.8	1 223	6.2	19 764
Spain	:	-	309	0.1	4 391	2.1	6 737	3.2	191 511	91.5	6 442	3.1	209 390
France	:	-	:c	-	164	0.1	1 040	0.7	1 718	1.1	150 655	98.1	153 580
Croatia	:c	-	49	0.5	328	3.1	337	3.2	411	3.9	9 315	89.2	10 439
Italy	:c	-	170	0.1	91 454	78.3	21 670	18.5	3 313	2.8	:c	-	116 820
Cyprus	:c	-	26	4.6	73	13.0	32	5.7	61	10.8	371	65.9	563
Latvia	:	-	11	0.1	198	1.3	228	1.6	11 449	77.9	2 804	19.1	14 690
Lithuania	:	-	23	0.1	1 560	5.9	1 411	5.3	21 184	80.0	2 307	8.7	26 485
Luxembourg	:	-	2	0.0	147	1.7	84	0.9	349	3.9	8 268	93.4	8 850
Hungary	:	-	81	0.2	1 435	3.7	2 249	5.9	29 548	77.0	5 041	13.1	38 353
Malta (³)	:	:	:	:	:	:	:	:	:	:	:	:	:
Netherlands	12	0.0	159	0.2	1 390	2.0	735	1.1	420	0.6	66 776	96.1	69 492
Austria	11	0.0	37	0.2	767	3.1	1 730	7.1	1 747	7.1	20 144	82.4	24 436
Poland	133	0.1	2 217	0.9	9 499	3.6	8 172	3.1	227 735	87.4	12 957	5.0	260 713
Portugal	16	0.1	178	0.6	708	2.2	1 752	5.5	28 101	88.3	1 080	3.4	31 835
Romania	:c	-	62	0.2	4 305	11.0	3 439	8.8	6 806	17.4	24 411	62.6	39 023
Slovenia	4	0.0	53	0.3	398	2.2	364	2.0	5 953	33.2	11 137	62.2	17 909
Slovakia	559	1.7	357	1.1	667	2.0	631	1.9	2 971	8.9	28 354	84.5	33 540
Finland	41	0.2	33	0.1	325	1.3	1 179	4.8	1 578	6.4	21 332	87.1	24 488
Sweden	:	-	:c	-	738	1.8	1 622	3.9	686	1.7	38 444	92.6	41 502
United Kingdom	175	0.1	2 428	1.5	8 270	5.2	11 520	7.2	28 395	17.9	108 136	68.0	158 924
Norway	:	-	6	0.0	849	3.7	3 066	13.3	410	1.8	18 805	81.3	23 136
Switzerland	8	0.1	48	0.4	302	2.4	382	3.1	9 741	78.3	1 960	15.8	12 441

Table 34: Road transport by gross vehicle weight of vehicle – 2015 (million-tonne-kilometres) Source: (Eurostat, 2016)

In terms of fleet age distribution, the EU-28 data is available in Eurostat (2016) which is summarised in Figure 30. The goods vehicle fleet is classified into five categories at country level. This figure shows that the age distribution of goods vehicles are broadly similar between the United Kingdom and the Netherlands, although the average age of the goods vehicles in the UK is slightly less than the Netherlands. Variations are also expected at the city level compared to the national level.

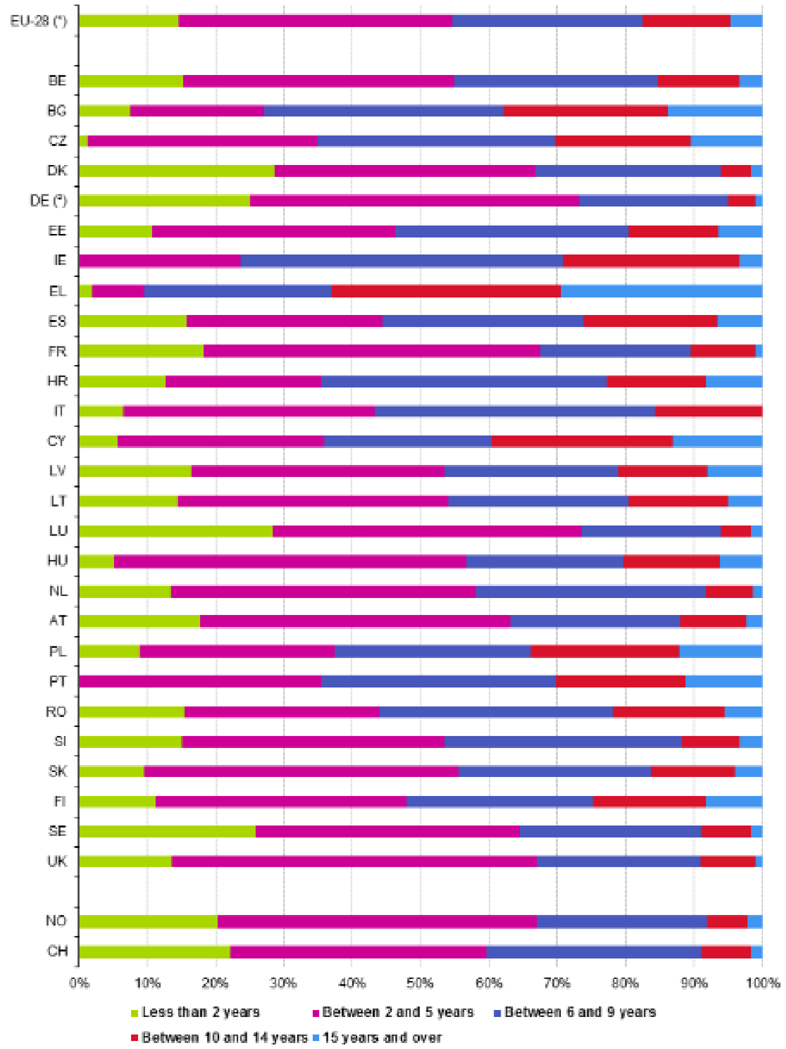


Figure 30: Share of age categories in road goods transport - 2015 (source: Eurostat)

For this FREVUE Amsterdam environmental impact assessment by different EFV penetration levels, due to the lack of data from Amsterdam on future fleet composition forecast, it is decided to use the London data instead. Although there are differences between the two cities, especially in terms of vehicle mileage share by goods vehicle with different gross vehicle weight categories as discussed above, there are also similarities, including the age distribution of goods vehicle fleet and the spatial distribution of heavy good vehicles.

3.3.5 Environmental impacts of EFVs at different market penetration levels

The process to calculate environmental impacts of EFVs at different market penetration levels is shown in Figure 31. The overall process is similar to what has been used in the London analysis with some variations. The impact analysis has been done for both forecast years (2020 and 2030) of the VMA model. Unlike the LoHAM model, the AADT flow can be obtained directly by summarising the modelled flows from three peak periods in VMA. Link based speeds are also extracted from each time period to be used for speed based emission estimation. The same version of the Emission Factor Toolkit (EFT) is used to calculate vehicle emissions, which are based on COPERT 4v11 speed functions. As discussed in section 3.3.4, the default London fleet composition forecast is used (further categorised by whether the link is a motorway or an inner-city link) as an approximation. All results are exhaust only.

As for London, analysis of environmental impacts is made separately based on three market penetration scenarios:

- low penetration: only 10% of the total freight vehicles are electrified
- medium penetration: 50% of the total freight vehicles are electrified
- high penetration: 100% of the total freight vehicles are electrified

For the baseline scenario, it is also assumed that all vehicles are conventional ICE vehicles. Results are then presented by comparing emission savings from different EFV penetration levels against the baseline scenario at different forecast years (i.e. 2020 and 2030 for Amsterdam).

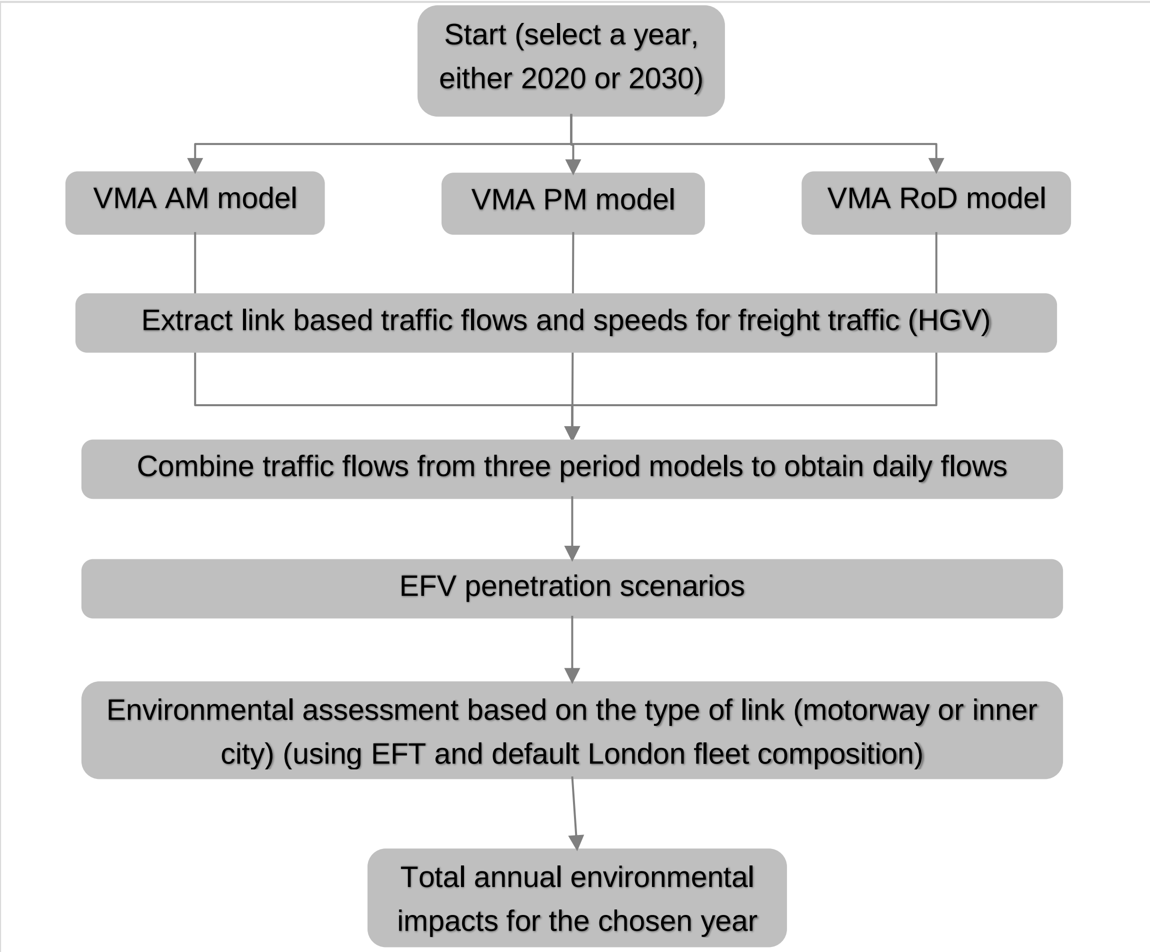


Figure 31: Environmental impact analysis using Amsterdam VMA model – flow chart

In year 2020, for the Amsterdam study area (Figure 27), the benefits from electrifying goods vehicle fleets include CO_2 savings of 310,000 tonnes per year, NO_x savings of 323 tonnes per year and exhaust PM_{10} savings of 3.4 tonnes per year, based on the assumption that all conventional vehicles are converted into electric vehicles. The benefits for medium and low penetration levels decrease as the percentage of EFV uptake levels reduce but significant amounts of emission savings are still expected.

In year 2030, similar to the London result, due to a wider deployment of the Euro VI/6 vehicles with better emission control technologies, the NO_x and PM_{10} reductions are much smaller comparing to 2020 results, with 135 tonnes and 1.4 tonnes savings per year respectively in the Amsterdam study area for the high penetration scenario. The CO_2 emission savings, however, increase to 316,000 tonnes per year due to increased vehicle mileage (Table 33) and the fact that CO_2 emissions are not related to emission standards. Similar patterns are observed for the low and medium penetration scenarios.

Emission reductions	Penetration levels		
2020	Low	Medium	High
CO_2 (tonnes)	30997	154983	309966
NO_x (kg)	32311	161554	323109
PM_{10} exhaust (kg)	341	1707	3413
2030	Low	Medium	High
CO_2 (tonnes)	31601	158007	316014
NO_x (kg)	13558	67791	135583
PM_{10} exhaust (kg)	145	725	1449

Table 35: Environmental impacts in Amsterdam in 2020 and 2030 at different EFV penetration levels

3.4 Conclusions

The second level analysis looks at potential environmental impacts by using traffic models at three different EFV market penetration scenarios. Two models have been obtained from FREVUE demonstration cities, including the LoHAM model from London and the VMA model from Amsterdam. The analysis on the spatial distribution of freight traffic from these models show that majority of the heavy goods vehicle flows (with gross vehicle weights of 3.5t or above) are concentrated around motorways or major roads. However, light goods vehicles (LGVs) use all types of roads. Therefore, more health benefits can be achieved by electrifying LGV groups due to their presence in residential areas and city centres.

Analysis of trip length distributions show that almost all HGV traffic has a journey length of less than 200km for the trips starting or ending in the study area (within M25 in London, and within eight Amsterdam boroughs), which means almost all trips are within the range that has been achieved by FREVUE demonstration vehicles.

Results from the level two analysis show that in year 2021, within the M25 area in London, the maximum benefits from electrifying goods vehicle fleets have a CO_2 savings of 2.8 million tonnes per year, NO_x savings of 4021 tonnes per year and exhaust PM_{10} savings of 38 tonnes per year, based on the assumption that all conventional vehicles are converted into electric vehicles. The benefits for medium and low penetration levels are smaller but a significant amount of emission savings can still be expected. In year 2031, due to a wider deployment of the Euro VI/6 vehicles with better emission control technologies, the NO_x and PM_{10} reductions are smaller compared to 2021 results, with 2489 tonnes and 16.8 tonnes savings per year respectively within the M25 area for the high penetration scenario. The CO_2 emission savings, however, increase to 2.9 million tonnes per year due to higher vehicle mileage which are predicted by traffic models. Analysis for Amsterdam also shows significant savings for the forecast years 2020 and 2030.

4 Monetising systemic and environmental impacts

The valuation of air pollution and climate change has been an area of active research interest. As a result, many scientific research papers have been published over the years to try to quantify these impacts (Welsch (2006), Desaigues et al. (2011) and van den Bergh and Botzen (2015)).

For the FREVUE impact valuation, we use the methods adopted by the UK's Department for Transport (DfT, 2015), which are described in detail in Transport Appraisal Guidance (TAG) Unit A3 – Environmental Impact Appraisal. TAG consists of software tools and guidance on transport modelling and appraisal methods that are applicable for highways and public transport interventions. These facilitate the appraisal and development of transport interventions, enabling analysts to build evidence to support business case development and to inform investment funding decisions.

It should be noted that the impacts valuation methods set out in the TAG guidance rely on the existence of a transport model to provide detailed traffic flow data, and the set of parameters supplied in the relevant TAG tables and spreadsheets are designed to be used in the UK. According to TAG, for the evaluation task such as the FREVUE impact assessment for different EFV penetration levels which are detailed in Chapter 3, valuation was carried out for air pollution, greenhouse gases and noise impact. These are discussed separately in the following sections.

4.1 Valuation of air quality impacts

As discussed in section 2.1.1, road transport is a significant source of local air pollution. For urban areas where population density is high, emissions from road traffic represent a significant proportion of pollutant concentrations (NO_x and PM), which affect people's health.

TAG suggests carrying out air quality valuation based on a hybrid approach, which combines the damage cost approach and marginal abatement cost approach (MAC).

Damage costs are based primarily on the health impacts of air quality pollutants. The damage costs for both NO_x emissions and PM_{10} concentrations are derived from health impacts arising from changes in NO_x emissions and PM_{10} concentrations respectively. Three values are provided, including a central value, a low value and a high value. The high and low values represent uncertainty around the potential time lag between a change in air quality and health impacts, ranging from a zero lag (for the high values) to a 40 year lag (for the low value).

by pollutant (2010 prices, 2010 values)	Central Value	Low value	High value
PM10 damage costs (£/household/1μg/m³)	92.7	48.6	105.4
NO_x damage costs (£/tonne)	955	744	1085
NO_x marginal abatement costs (£/tonne)	29,000	27,000	73,000

Table 36: Damage cost and marginal abatement cost values (source: TAG Data Book 2017)

The MAC approach has been developed for interventions that are expected to result in changes to air quality in areas exceeding EU limit values, or where those limits will be exceeded following the intervention. The MAC approach is further explained by TAG as follows:
"Application of the MAC approach does not imply that breaches of legal obligations can be permitted in cost-benefit terms but represents the indicative costs of additional abatement effort that would be required to comply with legal obligations if the scheme were to go ahead

(or savings from reduced abatement effort if the scheme results in an improvement). Therefore the MAC approach helps the delivery of legal air quality obligations by reflecting the need to deliver obligations and the costs associated with rectifying any breach". The values given in the Table 36 are indicative of the costs of a range of technologies that could form a marginal abatement option.

To derive the inputs for air quality valuation, total NO_x emissions and PM_{10} assessment scores based on concentrations are needed. The total NO_x emissions are already presented for London in Table 31 as a part of the Chapter 3 calculation. The PM_{10} inputs needed for valuation, however, require a different calculation process:

- Step 1: identify the affected network. In our London case, this includes all the links within the M25.
- Step 2: quantify the number of properties. This is to calculate the exposure to the change of air quality. The number of properties is required by a set of distance bands, which are set to give a close relationship to the diminishing contribution that vehicle emissions make to local air quality with increased distance. Typical bands used in the TAG are:
    1. Link centre to 50m from link centre
    2. 50m – 100m from link centre
    3. 100m – 150m from link centre
    4. 150m – 200m from link centre

  Beyond 200 m from the link centre, the contribution of vehicle emissions to local pollution levels is not significant.
- Step 3: calculate NO_x and PM_{10} concentrations. The annual mean concentrations should be calculated within each band for all affected route.
- Step 4: calculate property weighted NO_x and PM_{10} concentrations. This should be carried out for each of the four bands and the results added together give a total for the without scheme case and the with scheme case for each affected link.
- Step 5: calculate the number of properties that improve, deteriorate or stay the same and calculate a link score for each of the affected links.

However, it is not possible to carry out this 5-step analysis as the property location data in London is not available to Imperial and the size of the affected network exceeds more than 50,000 links. Therefore, the valuation of air quality impacts can only be carried out for NO_x in London.

Using TAG's air quality valuation worksheet[23], based on the forecasted NO_x savings in Table 31, the valuation for NO_x savings are calculated and presented in
Table 37. The analysis area covers the M25 motorway links and all the links inside the M25 area in London (see Figure 23).

Results are based on the 2017 price and are presented for both abatement costs and damage costs by different EFV penetration assumptions (defined in section 3.2.6) and by evaluation uncertainties (Table 36). The evaluation results are based on the comparisons between conventional ICE vehicles and uptake levels of EFV. For example, for the EFV low uptake level, represents a scenario that 10% of ICE vehicle kilometres from goods traffic are replaced by EFVs, with the remaining 90% of vehicle kilometres' goods traffic are still carried out by ICE vehicles. No other types of low emission vehicles are considered in this comparison.

[23] https://www.gov.uk/government/publications/webtag-environmental-impacts-worksheets

Valuation uncertainty	EFV uptake Low (PV)			EFV uptake Medium (PV)			EFV uptake High (PV)		
	abatement costs	damage costs	Total	abatement costs	damage costs	Total	abatement costs	damage costs	Total
Low	£524,835,791	£247,193,977	£772,029,768	£2,624,176,346	£1,235,968,654	£3,860,144,999	£5,248,352,691	£2,471,937,308	£7,720,289,999
Central	£563,712,516	£317,298,720	£881,011,236	£2,818,559,779	£1,586,492,022	£4,405,051,801	£5,637,119,557	£3,172,984,044	£8,810,103,601
High	£1,419,000,472	£360,491,216	£1,779,491,688	£7,094,995,305	£1,802,454,287	£8,897,449,592	£14,189,990,610	£3,604,908,574	£17,794,899,183

Table 37: Valuation of NO_x savings in London – 2021 (2017 price)

Valuation uncertainty	EFV uptake Low (PV)			EFV uptake Medium (PV)			EFV uptake High (PV)		
	abatement costs	damage costs	Total	abatement costs	damage costs	Total	abatement costs	damage costs	Total
Low	£0	£140,066,326	£140,066,326	£0	£700,331,632	£700,331,632	£0	£1,400,662,701	£1,400,662,701
Central	£0	£179,789,438	£179,789,438	£0	£898,947,189	£898,947,189	£0	£1,797,893,655	£1,797,893,655
High	£0	£204,263,393	£204,263,393	£0	£1,021,316,963	£1,021,316,963	£0	£2,042,633,105	£2,042,633,105

Table 38: Valuation of NO_x savings in London – 2031 (2017 price)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Urban (Road)	59.9%	55.2%	50.5%	45.7%	41.0%	36.3%	30.5%	24.8%	19.1%	13.3%	7.6%	6.4%	5.2%	3.9%	2.7%	1.5%	1.3%	1.1%	0.8%	0.6%	0.4%
National (Road)	17.1%	16.0%	14.9%	13.8%	12.7%	11.6%	9.8%	8.0%	6.1%	4.3%	2.5%	2.1%	1.7%	1.3%	0.9%	0.5%	0.4%	0.3%	0.3%	0.2%	0.1%
Rail	8.4%	7.7%	7.1%	6.4%	5.8%	5.1%	4.3%	3.5%	2.6%	1.8%	1.0%	0.8%	0.7%	0.5%	0.4%	0.2%	0.2%	0.1%	0.1%	0.0%	0.0%

Table 39: Percentage of links exceeding the EU limits (source: Defra & TAG air quality evaluation worksheet)

In year 2021, for a low EFV penetration level , damage costs are expected to reduce by 0.3 billion pounds for the central value Abatement costs, which are related to the percentage of links exceeding the EU limits (see the forecast provided by Defra in Table 39), are reduced by 0.5 billion pounds for the central value, although significant uncertainties can be expected for the abatement costs. Higher EFV penetration levels in year 2021 result in higher savings as shown in Table 37. A large proportion of these savings come from the abatement costs.

The results in year 2031 (Table 38) show that if there are 100% penetration levels of EFV for the study area, the damage costs are reduced by 1.8 billion pounds at the 2017 price for the central scenario. This value is less than the results in year 2021 because the absolute amount of NOx savings in year 2031 is less than in year 2021 (as shown in Table 31). The abatement cost benefits in year 2031 is zero as it is forecasted that there will be full compliance of the EU limits for all links in urban areas in the UK.

4.2 Valuation of greenhouse gas emissions

As explained by TAG, "when carrying out monetary valuation, it is important to distinguish between the emissions from those sectors that are included within the EU Emissions Trading System (EU ETS) – the 'traded sector' - and those that are not – the 'non-traded sector'. The traded sector covers emissions from power and heat generation; energy-intensive industry and aviation. For example, emissions arising from electricity consumption in transport are in the traded sector. The non-traded sector covers all other greenhouse gas emissions. Emissions from other types of transport fuel, including petrol, diesel and gas oil, are in the non-traded sector".

"The Department for Energy and Climate Change (DECC) publish guidance on valuing energy and climate change impacts. This sets out the methodology for carbon valuation in UK policy appraisal based on the estimated abatement costs per tonne of carbon dioxide equivalent to achieve the government's emissions targets. The method to be used for transport appraisal is consistent with DECC's guidance. The methodology depends on whether emissions are within the traded or the non-traded sectors".

For impact valuation in the non-traded sector, TAG data book (Table 40) gives the non-traded values in £ per tonne of CO_2e. The values in the table are based on those referred to in the DECC guidance. These values are estimated by the target-consistent marginal abatement costs consistent with the Government's commitments on greenhouse gas emissions. Higher and lower estimated values are provided for sensitivity analysis.

In the traded sector, because emissions are capped, this creates a market for GHG trading, which means companies can purchase EU allowances (EUAs) to cover relevant emissions. The cost of any EUAs to cover traded emissions is reflected in the purchase price of traded sector goods. The projections of the purchase price of traded sector transport fuel such as electricity therefore includes the future allowance purchase price.

However, for our wider environmental impact, we are not interested in the change of operational cost to a freight operator which is affected by the price of electricity. The holistic approach of looking at the valuation of total GHG loads, taking into account the GHG emissions from electricity generation, is more appropriate.

Year	Low	Central	High
2010	26.91	53.82	80.74

2011	27.32	54.63	81.95
2012	27.73	55.45	83.18
2013	28.14	56.28	84.43
2014	28.56	57.13	85.69
2015	28.99	57.98	86.98
2016	29.43	58.85	88.28
2017	29.87	59.74	89.61
2018	30.32	60.63	90.95
2019	30.77	61.54	92.31
2020	31.23	62.47	93.70
2021	31.75	63.51	95.26
2022	32.27	64.55	96.82
2023	32.79	65.59	98.38
2024	33.32	66.63	99.95
2025	33.84	67.67	101.51
2026	34.36	68.71	103.07
2027	34.88	69.75	104.63
2028	35.40	70.79	106.19
2029	35.92	71.84	107.75
2030	36.44	72.88	109.32
2031	39.82	79.64	119.47

Table 40: Non-Traded Values, £ per Tonne of CO2e (2010 prices) source: TAG data book

For London, the estimated exhaust only GHG emissions are available as a part of the analysis in Chapter 3 (Table 31). To obtain the total GHG emissions, it is necessary to estimate the impact of the transport scheme on energy assumptions.

TAG provides an estimation of electricity consumption per kilometre for cars. However, no figures are given for LGV and HGV vehicles. For our analysis, the FREVUE average figures from all demonstrators are used. Vehicles are grouped into two categories: LGV (GVW less than 3.5t) and HGV (with GVW equal to or more than 3.5t). Please note all of the FREVUE vehicles weigh less than 20t; however, based on the fleet composition forecast (Table 28), a sizeable proportion of the fleet are weighed at more than 20t. Therefore using the FREVUE electricity consumption figures is likely to underestimate energy usage, and therefore overestimate net GHG benefits. The FREVUE average energy consumption figure is shown in Table 41.

	Number of Vehicles with SoC data	Total Distance(km)	Total Electricity consumption (kWh)	Average consumption (kWh/km)
LGV	19	231,173	55,866	0.2417
HGV	77	512,118	386,737	0.7552

Table 41: FREVUE average energy consumption figures

By using vehicle kilometres data from the LoHAM model and electricity consumption data in Table 41, it is possible to estimate energy consumption by electrifying the goods vehicle fleet in year 2021 and 2031 (Table 42). It should be noted that the figures presented in this table are based on the high EFV penetration scenario.

	vehicle.km	Electricity consumption	Electricity consumption	Total

			rate (kWh/km)		(kWh)		(kWh)
	LGV	OGV	LGV	OGV	LGV	OGV	
2021	17,395,807	5,482,129	0.2416610	0.7551715	4,203,888	4,139,948	8,343,836
2031	19,252,682	5,414,727	0.2416610	0.7551715	4,652,622	4,089,048	8,741,670

Table 42: Electricity consumption by electrifying all freight traffic in year 2021 and 2031

TAG also provides GHG conversion factor forecasts for UK electricity, which is based on DECC (2015). For year 2021 and 2031, the electricity conversion factors are predicted as follows:

- 2021: 0.270 CO_2e/kWh
- 2031: 0.118 CO_2e/kWh

Based on these figures, the total GHG environmental reduction is predicted in Table 43. As the power sector is gradually decarbonised, the net percentage of GHG savings from electrifying freight traffic increases between 2021 and 2031. It is estimated that in 2031, the net GHG emission savings would exceed 2.5 $MtCO_2e$ by converting all freight traffic in to electric vehicles within the M25 area in London.

Year	Penetration levels					
	Low		Medium		High	
	Exhaust only	Total load	Exhaust only	Total load	Exhaust only	Total load
2021	284,242	207,496	1,421,212	1,037,485	2,842,424	2,074,970
2031	289,179	255,055	1,445,896	1,275,280	2,891,792	2,550,561

Table 43: Exhaust only and total GHG emissions by penetration levels in London 2021 and 2031 (tCO_2e)

Using DfT's greenhouse gases worksheet[24], based on the net GHG emission saving figures in Table 43, it is possible to monetise the greenhouse gases emissions.

Uncertainty	Penetration levels					
	Low		Medium		High	
	2021	2031	2021	2031	2021	2031
Low	£6,776,394	£6,129,221	£33,882,019	£30,646,126	£67,764,038	£61,292,251
Central	£13,552,789	£12,258,442	£67,764,038	£61,292,251	£135,528,077	£122,584,502
High	£20,329,183	£18,387,663	£101,646,058	£91,938,377	£203,292,115	£183,876,753

Table 44: Valuation of net GHG savings in London – 2021 and 2031 (2017 price)

Valuation results presented in Table 44 are discounted to a 2017 price. For the central scenario, it is predicted that the net benefits of GHG savings from electrifying all freight traffic within the M25 area in London is more than 122 million pounds, although the possible value can range from 61 million to 184 million pounds in year 2031. The net benefits decrease as penetration levels drop. However, it is still a sizeable benefit even at the 10% penetration level, with potential valuations between 6 million and 18 million pounds in 2031 alone for the study area in London.

[24] https://www.gov.uk/government/publications/webtag-environmental-impacts-worksheets

4.3 Valuation of noise impacts

Defra has produced guidance on assessing the impacts of transport-related noise from different sources, covering road, rail and aviation noise, using an ‘impact pathway’ approach and covering a range of impacts on:

- Annoyance
- Sleep disturbance, and
- Health impacts, including heart disease (acute myocardial infarction, or AMI) stress and dementia

A few areas of uncertainty are highlighted in the Defra’s guidance. These include, for example, the dose response function which describes how people are affected at different noise levels, the disability weights which are used to describe impacts in the unit of Disability-Adjusted Life Years (DALYs) and the monetary valuation of these impacts. In general, it is challenging to quantify noise impacts because noise depends on the precise geometric relationship of source and receiver. These relationships are often not available or expensive to acquire. For electric vehicles, there is the additional complexity of the relationship between engine noise and noise from tyres which is related to the speed of travel.

TAG suggests the following steps for valuation of noise impacts:

- Scoping, to decide a study area where the noise impact needs to be carried out
- Quantification of noise impacts, which normally are carried out using standard prediction methods, such as the calculation of Road Traffic Noise (CRTN - ISBN 0 11 550847 3) which was issued by the Department of Transport in 1988. The location of properties is also required to calculate the number of households experiencing different noise level bands.
- Estimation of affected population. A set of dose-response functions is used to calculate for each impact pathway the percentage of affected, or the increased risk of adverse health outcomes.
- Monetary valuation of changes in noise impact, is based on estimation of the number of Disability-Adjusted Life Years (DALYs) lost or gained under each impact pathway. The monetisation with a value of £60,000 per DALY. The methods and parameters are sourced from “Environmental noise: Valuing impacts on: sleep disturbance, annoyance, hypertension, productivity and quiet (Defra, 2014)”. More detail on the derivation of the values and underlying research is given in that report.
- Consideration of the distributional impacts of changes in noise

The change in noise level is usually calculated based on the change of traffic flows. However, in the FREVUE assessment, it is assumed that there is no change of freight traffic from electrifying the fleet. Hence by using standard calculation methods, there will not be any change of noise level. In addition, TAG also make the comment that the relationships in the Defra tool are based on data gathered in the past decade and further research is needed to assess the response to different sources of transport noise such as when traffic is not free flowing (i.e. urban traffic scenario).

Apart from the issues discussed above, additional challenges, such as the lack of property locations to calculate the number of affected households and the large number of links (impact pathways), mean that it is not possible to carry out the valuation for London under different EFV penetration levels. More research is needed in this area to create the evidence base which can be used for noise assessment and valuation of electric vehicles.

4.4 Other factors

Apart from air quality, GHG and noise impacts discussed above, there are potentially other impacts which may affect total valuations. These include, change of journey time and change of accident rate from the impacts of deploying electric freight vehicles.

It has been widely reported in the FREVUE project that the drivers enjoy fast acceleration of their electric freight vehicles. Some electric HGV drivers even reported that their vehicles accelerate faster than a normal car at road junctions. Therefore, it is very likely that the deployment of EFVs would have impacts on junction saturation flows. A saturation flow is a performance measure of junction operation. It is an indication of the potential capacity of a junction when operating under ideal conditions. Many factors may affect junction saturation flows, including the number of lanes, speed limits, traffic signal staging, the percentage of turning vehicles (left turn or right turn) and the percentage of heavy goods vehicles. A major study carried out by the Texas Transportation Institute shows that junction saturation flow decreases with an increase percentage of heavy vehicles (Bonneson et al., 2005) due to slow acceleration of these vehicles.

The replacement of conventional ICE vehicles with fast acceleration EFVs should in theory improve junction saturation flows therefore subsequently reduce journey time and delays to other road users. However, it is not possible to quantify or monetise this impact on the FREVUE project as detailed junction surveys and modelling are required. Although the overall impact on the journey time is likely to be positive, more research and analysis are needed.

The change of accident rate from deploying electric freight vehicles would also result in a positive or negative valuation impact depending on whether the accident rate increases or decreases. There are standard methods to monetise the change of accident rate, for example, the method used in COBALT to monetise accidents[25]. However, no statistics have been provided for electric vehicles and more research is required in this area.

4.5 Conclusions

This chapter summarised the monetary benefit of replacing ICEV with EFV. Using the results from the level two analysis, the level three analysis estimates the monetary values from air quality improvements and GHG reductions. Only London is analysed due to availability of key parameters. Methodologies detailed in the TAG were used in this analysis.

At the low penetration level for the year 2021 (10% uptake level), using the central value scenario (the most likely scenario), the total benefit from air quality improvements based on damage cost reduction is 0.3 billion pounds, and from GHG savings is 13.5 million pounds. In year 2031, the benefits of air quality improvement for a high penetration level are expected to reach 1.8 billion pounds, and the benefit of GHG savings is valued at 184 million pounds.

Apart from the monetary values calculated from air quality improvements and GHG savings, other factors may also bring sizeable economic impacts. These factors include noise impacts, reduction of journey times to other road users because of EFVs' fast accelerations at junctions and change of accident rates. However, due to insufficient data, monetary

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[25] https://www.gov.uk/government/publications/tuba-downloads-and-user-manuals

values were not able to be calculated for these factors under the FREVUE scenario. Given the significance of these impacts, the amount of economic benefits from wider environmental benefits should also be considered during the process of new policy evaluations.

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