Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Electric freight vehicles for urban logistics – technical performance, economics feasibility and environmental impacts

Yanjie Dong[a]*, John Polak[a], Terje Tretvik[b], Isabelle Roche-Cerasi[b], Hans Quak[c], Nina Nesterova[c], Tariq Van Rooijen[c]

[a]*Centre for Transport Studies, Imperial College London, London SW7 2AZ, United Kingdom*
[b]*SINTEF Technology and Society, Department of Safety and Mobility, S.P. Andersens vei 5, NO-7465 Trondheim , Norway*
[c]*TNO, Anna van Buerenplein 1, 2595 DA Den Haag, the Netherlands*

Abstract

This paper summarises the lessons learned from using electric freight vehicles (EFVs) for urban freight transport in three dimensions. First we look at the technical and operational suitability of using EFVs, including energy efficiency, range and its seasonal variations, and charging and local grid capacity issues. Then we examine all the elements which affect the business case from a carrier's perspective, including changes of business model by the size of the vehicle, changes in value network and the elements required to enable a transition towards a wider-scale electrification. Finally, we present the environmental impacts from running EFVs at three levels, including direct impact analysis from the project demonstration activities, impact analysis at a wider uptake level by using traffic models and impact monetisation. Data used for this analysis is collected under the European FP7 project FREVUE, where around 80 electric-powered vehicles were deployed in the cities of Amsterdam, Lisbon, London, Madrid, Milan, Oslo, Rotterdam, and Stockholm.

Keywords: electric freight vehicles; city logistics; electromobility; technical suitability; electric vehicles business case; environmental impacts

* Corresponding author. Tel.:+44 207 594 6105; fax:+44 207 594 6102.
E-mail address: y.dong13@imperial.ac.uk

1. Introduction

Road freight transport delivers many benefits to our society. It allows 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.

According to European Environmental Agency (EEA, 2016a), 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 are also contributed 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).

To respond to these challenges, the FREVUE project has deployed nearly 80 fully electric freight vehicles (EFVs), 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 with well-designed local policy.

This paper reports the main findings on technical performance of the EFVs, economic feasibility of electrifying urban logistics fleet and environmental impacts from EFV daily operations.

2. Technical Performance of EFVs

The technical suitability of EVs for logistics operations has been evaluated based on a monitoring program recording static and dynamic vehicle and charging data, as well as interviews with logistics operators, drivers and city managers.

Data was collected from more than a hundred electric freight vehicles across the FREVUE demonstrator cities. Gross vehicle weights ranged from 2.2 t to 19 t and battery capacities from 22 kWh to 200 kWh. The data collection period spanned from early June 2014 to mid-November 2016, and the 77 vehicles retained for detailed analyses consisted of 7 small vehicles (< 3.5 t), 54 medium sized vehicles (3.5 - 7.5 t) and 16 large sized trucks (> 12 t). The data covered 12 366 days of operation and a total mileage of 757 000 km. A detailed description and analysis of vehicle operational data can be found in FREVUE (2017c).

2.1. Performance analysis of small, medium and large electric freight vehicles

Key performance indicators

To be able to compare daily performance across all operators on equal terms, all trips were aggregated to single days of operation. Table 1 shows that energy spent per day or per km is as expected strongly related to gross vehicle weight of the vehicles. On average, these indicators are around four times larger for the large vehicle group compared to the small vehicle group.

We have no information about the load carried by the vehicles, but energy spent per gross vehicle weight and km driven can be computed. This proxy indicator shows that the large vehicle group is potentially as efficient, or even more so, as the other vehicle groups.

Km per kWh is decreasing with vehicle weight, and average range (km) is increasing with vehicle weight.

Table 1 Key performance indicators

Weight group	Distance (km) per day	Energy spent per day (kWh)	Energy spent per km	Energy spent per tonkm	Km per kWh	Average range (km)
< 3.5 t	77	16.2	0.23	0.12	4.8	106
3.5 - 7.5 t	43	23.0	0.65	0.11	1.9	115
> 12 t	64	60.6	1.01	0.07	1.1	170
Average	52	29.0	0.65	0.10	2.2	124

2.2. The effect of time of year on vehicle operation

Temperature and other climate parameters like humidity, precipitation and wind were collected from a worldwide weather service (yr.no), and connected to the data for each single trip. In the following, we examine how some key operational parameters vary across Europe by time of year.

Distance driven per kWh of energy

It is well known from the literature that the efficiency of electric cars is affected negatively both by extreme cold and by extreme hot weather. But, does the same apply to EFVs? The FREVUE data allows us to examine this question empirically. Fig. 1(a) shows how the average performance measured as Km per kWh vary by time of year for the three weight groups.

For small vehicles, the average efficiency is 27% higher during summer compared to during winter. For medium sized vehicles, there are small improvements in efficiency as the season changes from winter, through spring and till summer. For large vehicles, the average efficiency is about the same throughout the year.

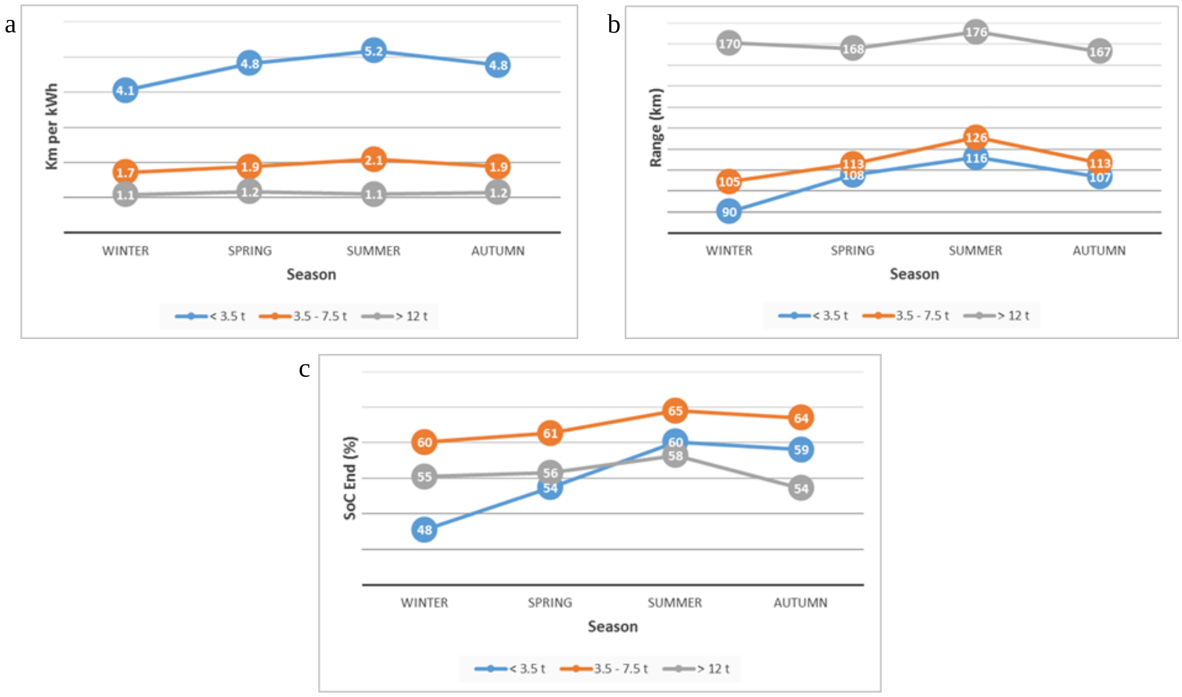

Fig. 1 (a) km per kWh; (b) range; (c) State of Charge at the end of the day

Range

Another question is whether the effective range of vehicles is affected by seasonal variations in temperature. Fig. 1(b) shows that the smaller vehicles have distinct and logical variations in range depending upon season of the year. The ranges during spring and autumn are almost identical, and the ranges during summer compared to winter are 29% longer for the small sized vehicles and 20% longer for the medium sized vehicles. The range of the largest vehicles is also longest during summer, but in general not to the same degree affected by season.

State of charge at the end of the day
One of the ways that operators can adapt to the fact that vehicles may have a lower range when the weather is cold is to take more energy out of the battery so that the state of charge is closer to zero at the end of the day.
Fig. 1(c) shows that all vehicle groups have their lowest average SoC at the end of the day during winter and their highest SoC at the end of the day during summer. This pattern is most distinct for the small vehicles and less distinct for the large vehicles.

This seems to indicate that operators are able to perform the same type of logistics work independent of season, by taking more or less energy out of the battery before the end of the working day.

2.3. Technical suitability of EFVs for urban last mile delivery

The demonstrations have shown that the electric vehicles are technically and operationally suitable for inner city freight operations. Some small and medium sized vehicles have limited range, and may need fast charging during the working day, especially in extremely cold weather. Light vehicles with low battery capacity may require charging twice a day, a short charging at lunchtime and a longer one during the night. Most of the large vehicles demonstrated seemed to have excess battery capacity for the logistics operations they were performing. They are charged during the night at their own dedicated post at their depot and are fully charged when leaving in the morning.

In general, the building of inner city fast charging infrastructure and new battery packs with higher capacity will further remove barriers for the operation of EFVs in cities.

Where larger fleets are electrified and charged at the depot, the local electricity supply might prove insufficient. A lesson learnt as a result of FREVUE is that it is essential to work with the distribution network operator in the process to identify possible constraints. It is expected that the types of operations the EVs will be able to be deployed for, will greatly expand in the coming years. New smart technologies will provide the necessary support to the management of the whole electricity distribution and to the integration of freight EV charging into the distribution network. By coordinating the demand between consumers and producers, the objective to only exploit green power could be also achieved. Smart charging will avoid peak loads on the power grid, waiting times for charging and drivers' anxiety. It should also be enabled into the fleet management systems, integration of booking charging times at designated posts and continuous recording of real-time SoC status to optimize the use of the fleet. Then, in case of a deviation, the vehicle data monitoring allows to adjust the trip and to use more battery capacity than the operators or drivers would take the risk to use today.

3. Examining the business case for EFV implementations

In total, more than 15 companies demonstrated the use of electric freight vehicles in city logistics operations under the FREVUE project, and the business case of all demonstrations are reviewed and documented in FREVUE (2017a). The results are presented below in three sections, including the change of business model, change in the value network and transition towards wide-scale electrification.

3.1. Change of business model by vehicle size

Fig. 2 shows a fully filled in business model canvas (BMC) that summarizes the main changes based on the experiences from FREVUE demonstrations. Note that not all items mentioned in the BMC are relevant for each case. The changes for a logistics operator are analysed when operating an EFV by a BMC comparison between the conventional freight vehicle (CFV) and EFV situation. The smaller EFVs in the demonstrations were used in a number of cases for last mile deliveries and led to changes in the logistics concept. Where they replaced Internal Combustion Engine (ICE) vehicles, they drove more fixed trips/routes and did less ad hoc pick-ups and deliveries. For the cases with medium electric freight vehicles no major changes were made to the logistics concepts, but in some cases the EFV trips were of shorter distance than the CFV trips and the EFVs did relatively more deliveries and fewer pick-ups than CFVs. For the cases with large electric freight vehicles it was very case-dependent whether or not changes were made to the logistics concept.

For all vehicle types there is a reduction of flexibility (because of range limitations and charging times) when it comes to the use of EFVs. However, the experiences in FREVUE show that with some adaptations to the operations, using EFVs in city logistics operations is well possible. This is especially the case when a company has such large volumes to deliver that it can also operate one or more ICE vehicles next to the deliveries with EFVs. In that case, the routes can be planned in a way that they best fit the positive characteristics of both the EFV and the ICE vehicles.

<table>
<tr>
<td rowspan="2">Key Partners
• Closer co-operation with cities via UCC and energy networks (0)
• New OEMs and dealers for EFVs are usually smaller and less professional than for ICEs (-)
• Fewer knowledgeable service men available for maintenance (-)</td>
<td>Key Activities
• Vehicle charging time (-)
• EFVs more difficult to plan due to range (-)
• Possible advantages due to policy exemptions/privileges (+)</td>
<td>Value Proposition
Limited changes: most customers want low emission deliveries, but willingness to pay is very limited at this moment (0)</td>
<td>Customer Relationships
No changes</td>
<td rowspan="2">Customer Segments
Customers including zero emission criterions in the procurement (+), although hardly used –at this moment – in practice</td>
</tr>
<tr>
<td>Key Resources
• Ownership of the vehicles: fewer lease options (0)
• Fuel costs vs. electricity (+)
• Procurement cost (-)
• Charging infrastructure required (-)</td>
<td>Value proposition for society
• Reduction of emissions (+)
• Less noise nuisance (+)</td>
<td>Channels
No changes</td>
</tr>
<tr>
<td colspan="3">Cost Structure
Investment costs: cost in purchase or lease of the vehicle; cost in purchase of charging point and telematics (-)
Operating costs (0) or in case of exemptions (+)
Training of drivers (-)
Less fuel costs; less maintenance costs (+)</td>
<td colspan="2">Revenue Streams
No changes (0), except if:
subsidy for the vehicle purchase (+), or for charging point purchase (+), zero emission in procurement (+), tax reductions (+)
Non-monetary revenue stream: more sustainable</td>
</tr>
</table>

Fig. 2 Business model canvas (BMC) for operators using EFVs – changes positive (+) neutral (0) or negative (-) compared to CFV situation (FREVUE, 2017a)

3.2. Changes in the value network

Logistics operators who decide to procure an EFV or more EFVs face challenges as the value network in which they act requires several changes. The logistics operator needs to establish new relationships as especially large vehicles cannot be procured from Original Equipment Manufacturers (OEMs) and charging infrastructure is not as widely available as fuel stations. In other words, for a logistics operator to currently switch from the existing diesel-powered vehicles towards electric powered vehicles, requires more than just buying another vehicle, as the logistics operator has to explore many new and uncertain areas. Extra effort is required in procuring EFVs in comparison to CFVs, as well as overcome sceptics in a traditionally conservative sector. These extra elements can be (and indeed turned out to be) a barrier for operators in moving from CFVs to EFVs, in addition to sometimes unfavourable total cost of ownership for EFVs. The development that OEMs will start producing these vehicles will be removing one barrier in the transition from CFV- to EFV-dominated city logistics, as the operator can then use the regular maintenance network and buy the vehicles from familiar suppliers.

The total cost of ownership (TCO) comparison between an EFV and a CFV is an important purchasing decision criterion for logistics operators. The TCO comparison results differ per vehicle type and usage. The TCO also depends on many other elements that can be country or even company specific.

For small electric freight vehicles, lighter than 3.5 tonnes, the TCO can be favourable for an EFV within about five years, in the case the vehicle drives 60 kilometres a day. The more kilometres the vehicle can be deployed on and the longer the (depreciation) period in which it operates, the larger the TCO advantage becomes for a small EFV. Small EFVs are already available from some OEMs, which reduce the purchase barrier even more.

For a medium sized electric freight vehicle, weighting between 3.5 and 7.5 tonnes, the TCO comparison shows that under specific circumstances a positive business case for using an EFV is, although challenging, possible (see also Fig. 3). The more kilometres an EFV drives the more favourable the comparison, as kilometre costs are lower for an EFV (lower costs for electricity instead of diesel and lower maintenance costs). Specific circumstances, like the exemption for paying the congestion charge for EFVs, have a very positive effect on the business case for the EFV, whereas major grid investments for charging larger fleet sizes affect the business case negatively. Next, many uncertainties still exist around the residual value.

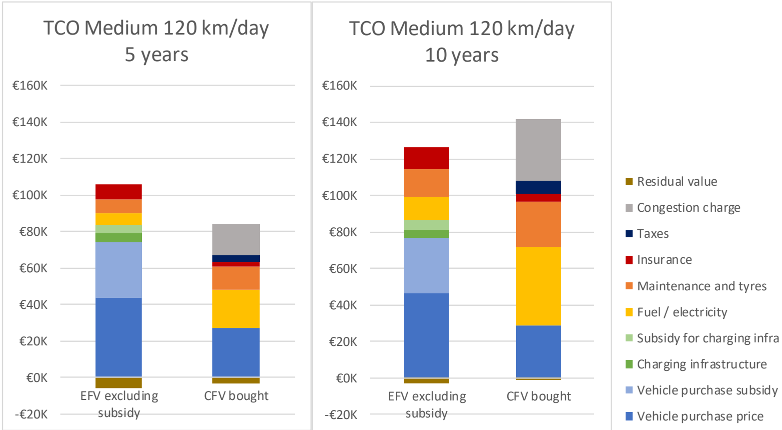

Fig. 3 Example of TCO comparison between medium sized vehicles with different mileage (FREVUE, 2017a)

For the large EFVs, divided into small rigids and medium rigids in the TCO comparison, the TCO of a CFV is lower than that of an EFV. The purchase price for the individually retrofitted large electric freight vehicle is currently so much higher than for the OEMs' conventional truck that advantages due to lower operational costs do not result in a positive business case for the large EFV. Even a depreciation time of ten years, and a (purchase) subsidy do not currently allow for a cost-neutral business case for a logistics operator. Notice that driving the maximum number of kilometres the battery allows (about 180 kilometres a day) paired with a purchase subsidy can almost result in a cost-neutral business case.

3.3. Transition towards wide-scale electrification

For a larger scale transition towards electric freight vehicles, which is necessary to achieve essentially CO_2 free city logistics in major urban centres by 2030, the reorganisation of existing diesel based and diesel evolved logistics systems is necessary. Reorganising the existing logistics concepts, in which the city operations are decoupled from the kilometres driven outside the city, are necessary to use the potential of electric freight vehicles for city logistics. There are different ways and forms to (re)organise city logistics in such a way that electric vehicles can be used for the last mile, such as the use of a dedicated hub by TransMission's Cargohoppers in Amsterdam, the use of an urban consolidation centre (Binnenstadservice in Rotterdam and as well as one in Stockholm), a cross docking centre (in Madrid), a decoupling point for swap bodies (in Rotterdam) and the setup of a construction consolidation centre. Such hubs allow for the transfer of goods somewhere near the city border from conventional vehicles to electric vehicles, so that the limited range of EFVs is not hindering city logistics operations. The examples discussed show that there is no easy proposition yet to convince existing logistics operators or shippers to use (or set-up) a zero emission alternative for city logistics operations.

To enable a large-scale transition towards full EFV fleets, the lower operational costs need to compensate the higher investment costs within the targeted depreciation period. Battery costs can be reduced by using a smaller battery. However to maintain the required daily mileage, fast charging then needs to be applied. Fast charging costs more than slow charging, which means that although the investment in the battery will decrease, the speed with which this smaller investment can be earned back will also be reduced. Where the battery price is the main price differentiator between the EFV and the CFV (as is expected with in-series produced EFVs), then reducing the battery size and (also) applying fast charging will decrease the earn back mileage. However if the price difference between the EFV and CFV is high and the battery price has less significance in this price difference (as is the case with CFVs that were converted into EFVs), then the reduction of the battery size in combination with applying fast charging might increase the earn back time.

At the current production scales for large EFVs (small series or even on a one-off basis) of companies converting CFVs to EFVs, the effect of volume on battery costs is limited. Furthermore, these companies are confronted with labour intensive (reverse) engineering activities, and are therefore unable to drive the production and maintenance costs significantly lower than the in-series produced vehicles.

Ultimately, a short-term market stagnation where transport companies are waiting for robust OEM products can be anticipated, given that they are faced with uncertainties on the purchase of higher priced products from conversion companies. This stagnation is not desirable, since there is a significant optimization potential by a combination of smart fleet planning and optimal charge regimes, as also seen from the partner scenario analyses. Here national or more localized legislation, and/or incentive programs, can play a significant role in encouraging the uptake of electric commercial vehicles in the next few years.

4. Environmental impacts from EFV implementations

Electric vehicles charged with low-emission electricity are one of the key options to reduce CO_2 emissions and air pollutants in road transport. Although extensive research has been carried out on the effects of electrification of passenger cars, the impacts from urban logistics fleet is relatively under researched.

Therefore, for this analysis the aim is 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). It 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, which should help better understanding 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. Detailed analysis can be found in FREVUE (2017b).

4.1. Direct environmental impact estimation

For road transport emission, there are three main pollutants of concern, including exhaust emissions, evaporative emissions and tyre and brake wear and road dust resuspension (Boulter et al., 2007). Among these, NO_x and PM are the emissions of greatest interest because of their effects on human health and the challenges faced by different cities to meet EU legislation which limits permissible ambient concentrations. For example, it is reported (TfL, 2014) that these two types of pollutants are the principal concern from road transport in London.

For our analysis, since the EFVs deployed at most of the FREVUE demonstrators are like-for-like replacements of conventional ICEVs with similar operational patterns, it is reasonable to assume that the abrasive emissions and resuspensions are similar between the two types of vehicles. In addition, the evaporative emissions from diesel fuel is negligible (EEA, 2016b). Therefore, the emission analysis will be based on hot exhaust only.

Based on the vehicle operation data which we have collected for all EFVs during the project, using COPERT 4 v11 model, the direct environmental benefits from FREVUE demonstrations are summarized in Table 2.

Table 2 Direct environmental impacts from FREVUE demonstration activities (FREVUE, 2017b)

	Euro III / Euro 3	Euro IV / Euro 4	Euro V / Euro 5	Euro VI / Euro 6
NOx reduction (g)	2,147,501	1,434,321	1,128,478	628,618
PM reduction (g)	72,174	23,513	8,948	1,430
Local GHG reduction (kgCO_2e)	400,073	386,821	387,402	385,610
Net GHG reduction (kgCO_2e)	190,371	177,184	177,612	175,833

Comparing with 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 hugely affected by the type of ICEVs that are replaced by EFVs, and our results confirm this. However, it is also noted that when comparing environmental benefits between EFV vs Euro III/3 and EFV vs Euro VI/6, there are significant differences between heavy goods vehicles and light goods vehicles, especially for the case of NO_x savings.

For example, in Rotterdam where most of the FREVUE vehicles are electric heavy goods vehicles (HGVs). The NO_x savings of replacing a Euro VI conventional HGV are around 15% of the NO_x benefits of replacing a Euro III conventional HGV. This difference of around 85% confirms the some of the tests conducted which have shown the effectiveness of Euro VI standards for HGVs, for example in Moody and Tate (2017), Robinson (2017) and TNO (2014).

However, in Madrid where all the electric vehicles are light good vehicles (LGVs), the difference of NO_x savings between Euro 3 and Euro 6 vehicles comparing with EFVs are only around 12%, which is also in line with a number of the reports about the ineffectiveness of emission control from some of the Euro 6 LGVs, for example, in Marner et al. (2016) and EEA (2016b). As new test procedures and the new Euro 6c standards are planned to be introduced, the emission performance for newer vehicles might be greatly improved in future.

When comparing PM benefits of Euro III/3 and Euro VI/6 with EFVs, due to the use of diesel particulate filter, significantly less PM emissions can be observed for both Euro VI (reduction up to 99%) and Euro 6 (reduction up to 97%) ICEVs, which lead to a much less PM benefits. However, there are no safe limits for fine particles ($PM_{2.5}$) hence any reductions are still hugely beneficial to human health.

In terms of the GHG savings, overall the project achieves 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 intensity, the total environmental GHG reduction is over 90%. However, for some operators in Rotterdam, the total environmental GHG reduction is very small. There might be a few reasons behind this, including:

- A high-carbon power. For example, UK emits over 30 times more CO_2 equivalents per kWh generated compared to Norway in 2015.
- Some of the Rotterdam vehicles have high percentage of high speed trips. Conventional ICE vehicles are much more efficient at higher speeds than lower speeds. Hence if a EFV is mainly used for high speed trips, its GHG saving benefits are smaller

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

4.2. Impacts at a wider penetration level

In order to estimate the impacts at different EFV penetration scales, strategic traffic models are required to provide key statistics, such as existing city traffic composition, traffic flow/network condition, freight demand and freight traffic distribution. Surveys were carried out with each of the FREVUE cities to identify whether suitable existing traffic model is available and in the end the LoHAM traffic model from London and VMA traffic model from Amsterdam were obtained. The following results are presented based on the analysis using LoHAM model.

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

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

The emission reductions based on different penetration levels for the Greater London area (within the M25 motorway) is shown in Table 3.

Table 3 Environmental impacts at a wider uptake level in London (FREVUE, 2017b)

Emission reductions	Penetration levels		
Year 2021	Low	Medium	High
CO_2 (tonnes)	284,242	1,421,212	2,842,424
NOx (kg)	402,138	2,010,688	4,021,376
PM10 exhaust (kg)	3,836	19,181	38,361
Year 2031	Low	Medium	High
CO_2 (tonnes)	289,179	1,445,896	2,891,792
NOx (kg)	248,930	1,244,650	2,489,299
PM10 exhaust (kg)	1,686	8,432	16,863

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.

4.3. Impact monetisation

The valuation of air pollution and climate change has been an area of active research interest. As a result, many research papers are published over the years to try to valuate these impacts from different perspectives. For this FREVUE impacts 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 and only London is analysed due to the availability of key parameters. 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 typical health impacts arising from changes in NOx 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). Due to data requirement of residential property locations for PM related valuation which we do not hold, valuation is only carried out for NO_x emissions only.

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. This 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 valuation of greenhouse gas emissions is based on the non-traded values in £ per tonne of CO_2e. 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.

The results show that at the low penetration level for the year 2021 (10% uptake levels), using 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.

5. Conclusions

The electric freight vehicles deployed as a part of the FREVUE project have demonstrated to be technically and operationally suitable for inner city freight operations. Although route optimisation might be required for smaller sized vehicles with limited battery capacity, most of the operators were able to replace ICEVs with EFVs directly without major issues.

Analysis shows significant air quality benefits from running EFVs instead of conventional diesel vehicles. However, the benefits diminish as the EURO standards of ICEVs improve. On the GHG emissions the net benefits strongly depend on the electrical grid carbon intensity and variations can be observed across different cities. As the power sector is gradually decarbonized, the net GHG benefits from running EFVs are likely to increase further in future. Using London as an example, our analysis also shows that even a 10% EFV penetration level would bring significant environmental and economic benefits.

The total cost of ownership (TCO) comparison between an EFV and a CFV shows that for small EFV (lighter than 3.5 tonnes) and in certain conditions for the medium sized EFV (between 3.5 and 7.5 tonnes), the TCO can be favourable. However, for the large EFVs, the TCO an EFV is unfavourable at the current condition. Apart from TCO, logistics operators are also facing other challenges such as the need to establish new relationships, lack of charging infrastructure and suitable OEM products. Hence national or more localized legislation, and/or incentive programs, can play an important role in encouraging the uptake of electric commercial vehicles in the next few years.

6. References

BOULTER, P., MCCRAE, I. S. & BARLOW, T. J. 2007. *A review of instantaneous emission models for road vehicles* [Online]. TRL Limited. Available: https://trl.co.uk/reports/PPR267 [Accessed].

DFT. 2015. *TAG UNIT A3 - Environmental Impact Appraisal* [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/487684/TAG_unit_a3_envir_imp_app_dec_15.pdf [Accessed].

EEA. 2016a. *Air quality in Europe — 2016 report* [Online]. Available: http://www.eea.europa.eu/publications/air-quality-in-europe-2016 [Accessed].

EEA. 2016b. *Explaining road transport emissions - A non-technical guide* [Online]. European Envirmental Agency. Available: http://www.eea.europa.eu/publications/explaining-road-transport-emissions [Accessed].

FREVUE 2017a. D3.2: Economics of EVs for City Logistics - Report.

FREVUE 2017b. D3.3 Systemic Transport and Environmental Impact of EFVs in Logistics - Report.

FREVUE 2017c. Publishable Executive Summary of D3.1 Technical Suitability of EVs for Logistics.

MARNER, B., MOORCROFT, S. & LAXEN, D. 2016. *Emissions of Nitrogen Oxides from Modern Diesel Vehicles* [Online]. Available: http://www.aqconsultants.co.uk/getattachment/Resources/Download-Reports/Emissions-of-Nitrogen-Oxides-from-Modern-Diesel-Vehicles-210116.pdf.aspx [Accessed].

MOODY, A. & TATE, J. 2017. In Service CO2 and NOX Emissions of Euro 6/VI Cars, Light- and Heavy- dutygoods Vehicles in Real London driving: Taking the Road into the Laboratory. *Journal of Earth Sciences and Geotechnical Engineering,* 7**,** 51-62.

ROBINSON, B. 2017. *Emissions Testing of Urban Delivery Commercial Vehicles* [Online]. Low Carbon Vehicle Partnership. Available: https://locity.org.uk/wp-content/uploads/2017/01/LowCVP-TfL-2016-Test-Programme-Final-Report.pdf [Accessed].

TFL. 2014. *Transport Emissions Roadmap - Cleaner transport for a cleaner London* [Online]. Transport for London. Available: http://content.tfl.gov.uk/transport-emissions-roadmap.pdf [Accessed].

TNO. 2014. *The Netherlands In-Service Emissions Testing Programme for Heavy-Duty 2011-2013* [Online]. Available: https://www.tno.nl/media/3443/hdv_in_service_testing_tno_2014_r10641.pdf [Accessed].

WHO. 2013. *Review of evidence on health aspects of air pollution – REVIHAAP project: final technical report* [Online]. Available: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report [Accessed].

WHO REGIONAL OFFICE FOR EUROPE, O. 2015. Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. Copenhagen: WHO Regional Office for Europe.