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Electric light commercial vehicles: Are they the sleeping giant of electromobility?

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ABSTRACT

Transport emissions need to be drastically decreased in order to put Europe on a path towards a long-term climate neutrality. Commercial transport, and especially last mile delivery is expected to grow because of the rise of e-commerce. In this frame, electric light commercial vehicles (eLCVs) can be a promising low-emission solution. Literature holistically analysing the potential of eLCVs as well as related support policies is sparse. This paper attempts to close this research gap. To this aim, the total cost of ownership (TCO) comparisons for eLCVs and benchmark vehicles are performed and support measures that target the improvement of the eLCV TCO are analysed. Various eLCV deployment scenarios until 2030 are explored and their impact on carbon dioxide (CO_2) and other pollutant emissions as well as pollutant concentrations are calculated. It is found that while in several European Union (EU) countries eLCVs are already cost competitive, because of fiscal support, some remaining market barriers need to be overcome to pave the way to mass market deployment of eLCVs. High penetration of eLCVs alone can lead to a reduction of total transport CO_2 emissions by more than 3% by 2030. For pollutant emissions, such as nitrogen oxide (NO_x) and particulate matter (PM), the reduction would be equal or even higher. In the case of PM, this can translate to reductions in concentrations by nearly 2% in several urban areas by 2030. Carefully designed support policies could help to ensure that the potential of eLCVs as a low-emission alternative is fully leveraged in the EU.

1. Introduction

The transition to a climate neutral economy is one of the key priorities for the European Union (EU) and a main element of the European Commission (EC) long-term strategy for 2050 (European Commission, 2018). The transport sector is one of the main levers of development but also a main carbon dioxide (CO_2) and pollutant emitter. In 2017, the transport sector was responsible for ca. 27% of the EU total greenhouse gas (GHG) emissions and light commercial vehicles (LCVs) produced around 9% of the 2017 EU transport GHG emissions (EEA, 2019a). According to the European Environment Agency (EEA) (2018), the average CO_2 emissions from new light duty vehicles (LDVs) increased for the first time since 2010 in 2017 and continued to increase in 2018 (EEA, 2019b).

Transport electrification is one of the solutions with the greatest potential towards decarbonised and sustainable transport systems. To this aim, the introduction of low and zero emission vehicles could actively support the decarbonisation of transport and the mitigation of emissions of internal combustion engine powered mobility (Hall and Lutsey, 2017). During the past decade, electric vehicles (EVs) have been increasing their market penetration, turning from a niche market to a growing reality (Thiel et al., 2020).

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Due to its large share, the passenger car (PC) category has attracted most of the users' attention, offering a greater number of model options from various manufacturers. Similar to PCs, the LCV category has shown an increasing trend in terms of new registrations of EVs in the past years (Tsakalidis and Thiel, 2018).

Additionally, LCVs are extensively used in commercial fleets, which can benefit the uptake of EVs in several ways. Typically, fleet managers base their decisions on rational arguments, which makes them more likely to take into account the total cost of ownership (TCO) and the lower operating costs of electric light commercial vehicles (eLCVs) compared to conventional vehicles, in particular for vehicles covering high annual mileages. Unlike private users, they can also predict the patterns of movement of their fleet reliably, allowing them to manage range limitations and recharging intervals. Moreover, fleet recharging infrastructure can be installed centrally in a fleet depot (Quak et al., 2016b; Frenzel, 2016).

Furthermore, some of the overarching societal trends, such as the increase in e-commerce and home-delivery, will lead to a much higher demand for light commercial transport, as more frequent deliveries will require more tonne-kilometres of last mile deliveries especially in urban and suburban areas (Dablanc et al., 2017; Kaplan et al., 2016; Wolff and Madlener, 2019). Through the Covid-19 crisis in spring and summer 2020 this trend has further been accelerated. The resulting increased demand will, at least partially, have to be covered by zero tailpipe emission LCVs, so that the achievement of the GHG emission and air quality targets of countries, regions, and municipalities are not compromised. In addition, Lin et al. (2018) highlight that same-day-delivery in e-commerce will lead to a further growth of fuel consumption and emissions in transport if internal combustion driven vehicles are used. Thus, zero tailpipe emission delivery models may be required even for this trend to mitigate its environmental impacts. Numerous small LCVs are devoted solely to short-distance trips and many often have a recurring daily route and use patterns when they are used as delivery vehicles. Generally, commercial fleets are parked overnight at dedicated parking depots, where fleet operators can manage their use more efficiently through centralised management systems. Moreover, fleets of LCVs, often used in confined spaces to fulfil specific duties (e.g. airports, industrial facilities), can also be managed centrally. Therefore, a recharging infrastructure on the companies' premises that would allow the recharging events to be easily managed and scheduled could be very useful.

In this context, the acquisition of LCVs and the development of fleets of vehicles in this category is highly dependent on their cost-effectiveness and reliable performance, with TCO being a decisive factor for fleet managers.

All the aforementioned elements can be influential in the acceptance of eLCVs, since barriers that have a negative effect for regular passenger vehicles (i.e. range barriers and recharging infrastructure availability challenges (Tsakalidis et al., 2019)) can be overcome more easily, while electricity can be a more attractive fuel alternative in terms of costs (Camilleri and Dablanc, 2017).

This paper aims at providing a comprehensive analysis of the recent eLCV deployment and future prospects in the EU, based on a two-pillar approach that covers both the economic and environmental aspects related to a greater market uptake of eLCVs. It focuses on the development of EVs, encompassing a country-by-country analysis of new EV registrations and registration shares, associated policy measures and the detection of early signals indicating future trends for eLCVs in the EU, covering battery electric vehicles (BEVs). This study performs an updated TCO analysis of eLCVs, in comparison to their conventional alternatives, taking into account the latest progress in cost reduction. Climate, energy and air quality impacts of ambitious eLCV deployment scenarios are evaluated. Hence, a gap in the literature is filled, as so far, no other study was found to have performed a comprehensive assessment of the economic and environmental aspects of eLCVs. The analysis focuses on LCVs, which in this study are defined equally to the N1 vehicle segment, based on the United Nations Economic Commission for Europe (UNECE) standards and the Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007, establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles. N1 vehicles are *designed and constructed for the carriage of goods, having a maximum mass not exceeding 3.5 tonnes*, while passenger cars fall under the M1 category that includes vehicles *designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat* (European Union, 2007; United Nations Economic and Social Council, 2017).

2. Relevant research and policy background

2.1. Research related to the electrification of light commercial vehicles

The majority of the existing literature on eLCVs focuses on TCO analyses, fleets' electrification suitability, fleet managers' as well as users' acceptance and policy support measures:

2.1.1. Total cost of ownership analyses

By applying a TCO model for the United States (US) market, Feng and Figliozzi (2013, 2012) concluded that eLCVs would become highly competitive versus a benchmark diesel-propelled vehicle when the price of the EV variant would decrease by 10 to 30%, a decrease that has been overachieved since their study was conducted. In a TCO study for the Brussels Capital region in Belgium, Lebeau et al. (2015) showed that eLCVs have a lower TCO than petrol and diesel alternatives, starting from annual mileages above 16,000 km. They also stated that a battery price reduction of 25 to 75% would be required to make eLCVs the most competitive alternative even for lower annual mileages. In their comparison of small-sized EVs, such as tricycles and cargo cycles, versus diesel vans for last mile delivery of parcels, Melo et al. (2015) found that the EV environmental impact on city logistics is favourable but is accompanied by higher delivery costs. In their study, Lebeau et al. (2015) point out that from a TCO perspective, electric delivery quadricycles can be operated at lower costs than diesel and gasoline propelled N1 vehicles in the Brussels Capital region, since the BEV alternatives receive subsidies from the region.

2.1.2. Suitability of vehicle fleets for electrification, based on driving patterns and technical constraints

Based on statistical data on corporate fleets in Austria and Germany, such as number of vehicles and daily mileage as well as number of trips, Klauenberg et al. (2016) analysed which commercial sectors would be best suited to electrify their PC and LCV fleets. They then studied, with the help of global positioning system (GPS) data tracking, selected corporate fleets in more detail, concluding that the production and trading sector is the best suited for the electrification of its LCV fleet in Austria, while in Germany it is the wholesale and retail trade as well as the transportation and storage sectors. A similar study was performed by Christensen et al. (2017) on Denmark and Germany. They identified the construction, health and other services sectors as suitable for the use of eLCVs in both countries. Figenbaum (2018) studied the suitability of electrifying LCVs for craftsmen and service enterprises in Norway, analysing the driving patterns of LCVs on the basis of a two-week data logging and concluded that 42% of diesel LCVs could be replaced by eLCVs with a range of 170 km. All three studies (Christensen et al., 2017; Figenbaum, 2018; Klauenberg et al., 2016) agree that the range of eLCVs currently remains an important technical barrier towards a higher uptake of these vehicles.

2.1.3. Surveys of fleet managers, drivers, and policy makers

Sierzchula (2014) surveyed 14 American and Dutch companies that used EVs, PCs and LCVs, in their corporate fleets. While the scope of this study was beyond eLCVs, it is interesting to note that at the time of the survey fleet managers identified 'testing new technologies' as the main reason of their initial adoption of EVs. Quak et al. (2016a) report their findings from a large field operational test of eLCVs in Europe, the Freight Electric Vehicles in Urban Europe (FREVUE) project. They stress that the TCO of eLCVs is still less favourable than the one of conventional LCVs. Companies testing eLCVs were in general satisfied with their technical performance. The main weaknesses pointed out were higher eLCV purchase costs, their limited payload, limitations in after-sales support, issues with grid adequacy for depots with larger eLCV fleets and limited vehicle options available. According to the existing literature, eLCVs appear to have become a non-negligible alternative for fleet managers after 2015. Kaplan et al. (2016) have developed a model for the intentions of eLCV procurement for commercial fleet managers, based on the results of 1,443 responses of a survey of small and medium enterprises in Austria, Denmark and Germany. Out of the surveyed companies, only 27.2% were not interested in the purchase of eLCVs, while the rest were considering it as a possible future option (34.2%), at a preliminary or advanced reflection of using eLCVs (30.2%) and 7.7% were either preparing the procurement or had already bought at least one eLCV for their fleet. In a choice-based conjoint analysis based on 45 respondents from transport companies located in the Brussels Capital region, Lebeau et al. (2016) studied the attitudes of the respondents regarding the main attributes of LCV choices, such as purchase price, operating costs, environmental performance, range, refuelling/recharging time and payload. The respondents perceived the limited public recharging infrastructure and the limited range and high purchase prices of eLCVs as the main disadvantages. On the contrary, they identified the possibility to charge at the depot, low operating costs and environmental performance as their main advantages. The results of the conjoint choice experiment also provided the most important policy support measures, as viewed by the respondents. These were subsidies or tax exemptions as well as the deployment of publicly accessible fast charging stations. Morganti and Browne (2018) interviewed 15 last mile urban freight and service operators that use eLCVs and eight policymakers in Paris and London to identify the main technical and operational obstacles in the daily use of eLCVs and their view on the main policies necessary to overcome these obstacles. The main obstacles for eLCVs highlighted by the respondents are: the limited range, lack of public recharging points, payload restrictions and the need for grid reinforcements when installing recharging stations at their depot or warehouses. Wolff and Madlener (2019) surveyed 66 drivers at the German postal service with reference to their perceived satisfaction and perceived efficiency of eLCVs. They concluded that if drivers were able to choose their own LCV option, the majority would be in favour of eLCVs.

2.1.4. Studies on policy support measures

Several of the aforementioned surveys also assessed policy support measures. Subsidies and tax exemptions are considered in the literature as important to improve the relative TCO disadvantage of eLCVs (Christensen et al., 2017; Figenbaum, 2018; Klauenberg et al., 2016; Lebeau et al., 2015, 2016; Quak et al., 2016a; Sierzchula, 2014). Figenbaum, nevertheless, points out that the Norwegian example of favourable TCO conditions for eLCVs over conventional LCVs still did not lead to a significant uptake of eLCVs, due to their limited range. A possible alleviation of this barrier could be to incentivise or support the deployment of publicly accessible fast recharging points, as pointed out by Lebeau et al. (2016) and Morganti and Browne (2018). Banning polluting LCVs from parts of the city is mentioned by Lebeau et al. (2016) as a powerful support measure for eLCVs. Lebeau et al. (2016) and Morganti and Browne (2018) point out that extending the time windows for delivery by eLCVs, which could be justified by their low noise levels, would be another support measure that can increase the competitive position of eLCVs. Quak et al. (2016a) also seem supportive of this idea as they call for a more integrated city management approach and general support of less polluting vehicles. Sierzchula (2014) and Klauenberg et al. (2016) consider important to give organisations the possibility to test eLCVs, for example in the context of demonstration projects. This may be of less significance now, as several demonstration projects have already taken place (Foltyński, 2014; Quak et al., 2016a). An important support measure to remove a technical barrier, the limited payload, was highlighted by Morganti and Browne (2018), Klauenberg et al. (2016), and Christensen et al. (2017); they propose as a support measure the possibility for drivers to drive eLCVs up to a gross vehicle weight of 4.25 tonnes (instead of 3.5 tonnes) with a type B driving licence, thus alleviating the weight penalty, typically above 500 kg, from the batteries of eLCVs. This change has been done and is effective in Germany since the end of December 2014 (BMJV, 2014), in Austria since January 2017 (Electric Mobility Europe, 2019) and in the United Kingdom (UK) since 2018 (The Motor Vehicles (Driving Licences) (Amendment) Regulations 2018, 2018). Together with the EV support incentives this has led to a surge in eLCV registrations in Germany from 2015 onwards. Taefi et al. (2016) performed a multi-criteria analysis of policy measures in Germany, on the basis of the ratings provided by ten policymakers and eight fleet managers. The highest ranking policy measures identified in their study were fiscal support measures, public procurement of eLCVs and the extension of the scope of the type B driving licence for eLCV drivers. Mirhedayatian and Yan (2018) developed and employed an optimisation model to evaluate policy options for eLCVs under consideration of externalities and total welfare. They concluded that zonal fees for low-emission zones lead to higher welfare increases when compared with purchase subsidies and vehicle tax measures.

2.2. Policy context development in Europe

Starting from 2009, mandatory emission reduction targets for new cars were adopted by the EU legislation, with the first targets applied at the beginning of 2015, while CO_2 emission targets for LCVs registered in the EU were set in 2011 (European Commission, 2019a).

Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles requires that energy and environmental impacts linked to vehicles operation over their entire lifetime are taken into account in all purchases of road transport vehicles (European Parliament and Council of the European Union, 2009). In the 2011 White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' COM(2011)144 final, specific goals for a competitive and resource efficient transport system were set towards achieving a 60% reduction in GHG emissions. In this context, large fleets of urban buses, taxis and delivery vans were highlighted as being particularly suitable for the introduction of alternative propulsion systems and fuels to potentially contribute in reducing the carbon intensity of urban transport, in line with a strategy for near- 'zero-emission urban logistics' by 2030 (European Commission, 2011).

According to the Regulation (EU) No 510/2011, member states (MSs) are required to record information for each new LCV registered in the EU. Each member state is required to submit annually to the EC all the information related to their new registrations including specific CO_2 emissions (European Parliament and Council of the European Union, 2011). Moreover, with Regulation (EU) 2019/631 of 17 April 2019, the EU set CO_2 emission performance standards for new passenger cars and for new LCVs in order to contribute towards achieving the EU target of reducing its GHG emissions (European Union, 2019).

Supplementary to the aforementioned legislative level, in May 2017, the EC adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package. It highlights the key research and innovation (R&I) areas and priorities related to transport aiming at a clean, connected and competitive mobility transformation. These areas are arranged in seven roadmaps including a dedicated roadmap on Transport Electrification (European Commission, 2017a). STRIA is complementary to the 2015 Strategic Energy Technology (SET) Plan (European Commission, 2015).

A series of milestones of the Implementation Plan for Electrification in Road Transport have been introduced in the Transport Electrification roadmap. Specifically, there is a 2020 milestone with reference to *Deployment* calling for *5–10% market share for electric passenger cars and even higher in the urban environment (bikes, buses, vans)*. Then, a 2030 milestone for *60% market share for electric vehicles, half of those battery-electric, and 100% in the small vehicle segment* and a 2050 milestone for *100% CO_2-free road transport, mostly electric and minor portion of vehicles powered by other fuels*. Additionally, there is a 2020 milestone with reference to *Product Development and Operating Models* calling for *business models based on total-cost-of-ownership considerations (*e.g. *fleet applications, car sharing, delivery vans)* (European Commission, 2017b).

Moreover, the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS) is an open-access transport information system that analyses technology trends, research and innovation capacities and developments in the European transport sector, providing open-access information in accordance to the seven STRIA roadmaps, including Transport Electrification (Tsakalidis et al., 2018).

3. Materials and methods

As the main goal of this paper is to provide analysis of the status and future potential of eLCVs, a two-pillar methodological approach is implemented, covering the economic and environmental aspects related to the greater uptake of eLCVs. Provided that eLCVs fulfil all necessary technical performance requirements, their economic performance is the main driver for fleet operators to include them in their fleets. For policy makers, the environmental performance of eLCVs is the main rationale to introduce temporary support policies in order to overcome market barriers. Fig. 1 provides an overview of the methodological approach used in this study.

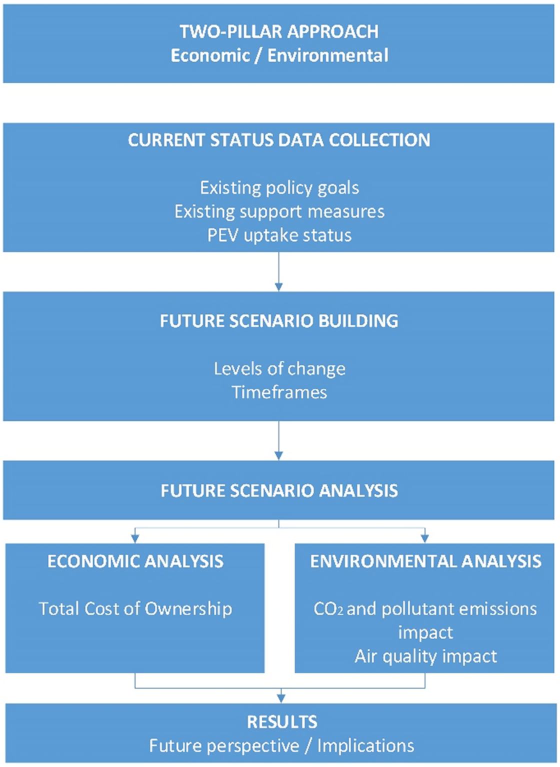

Fig. 1. Methodological approach overview.

3.1. Current status data collection

As a first step, the fleet data necessary for the analysis are collected focusing on both the current situation of EV uptake, future targets and relevant timeframes according to the existing policy goals. For present data, a series of relevant sources can be used including, inter alia, the European Alternative Fuels Observatory (EAFO), the EEA and Eurostat. Another main element that is taken into consideration is the support measures that have been used in many countries as levers for developing electro-mobility. The data collected should allow the comparison between markets of different sizes and levels of motorisation (i.e. LCV new registrations, eLCV registrations and share, and PC new registrations, electric PC (ePC) registrations and share).

3.2. Future scenario building

This step includes the development of future scenarios for the potential electrification of LCVs. Thus, in order to quantify the impacts of a potential rapid uptake of eLCVs on CO_2 and air pollutant emissions in Europe, an ambitious “eLCV scenario” as well as a “Benchmark” scenario are developed for comparison.

3.3. Total cost of ownership analysis

The total cost of ownership provides a summary metric of the costs vehicle use causes over time, summarising one-time benefits and payments (e.g. upfront payments, purchase subsidies), use-based costs (fuel or energy costs, maintenance) and periodic or occasional costs (e.g. insurance, repair), condensing them into a present value. It can be used as a metric of economic attractiveness of different options from a user or societal perspective. For LCVs, which are typically bought and operated by companies or fleet operators focusing on the economics of different options, TCO is an important element in purchase decisions. A comparison of TCO for eLCVs and their conventional counterparts can shed light on whether economic barriers to eLCV market uptake persist.

In this paper, TCO comparisons are carried out for present conventional LCVs and eLCVs of three sizes, i.e., small: <1.8 t, medium: 1.8 to 2.5 t, and large: 2.5 to 3.5 t gross vehicle weight, respectively. The analysis is based on the DIONE cost assessment methodology developed by the Joint Research Centre (JRC) in the framework of the analysis of EU post-2020 CO_2 emission standards, documented in Krause et al. (2017).

Three cost types are included:

a) Base vehicle and technology costs

The DIONE cost assessment methodology defines standard conventional vehicles of different sizes and segments in the base year 2013 in terms of their fuel efficiency characteristics and production costs. For these base vehicles, cost curves have been developed to specify the additional costs for either conventional vehicles to improve fuel efficiency, or for alternative powertrains, e.g. for BEV, to change the propulsion system, add the battery etc. needed to reach a given energy consumption reduction compared to the baseline vehicle. These costs are referred to as 'technology costs', which add to the base vehicle costs. According to the EEA (2018), new LCV average CO_2 emissions dropped to 158 gCO_2/km, indicating a 17% reduction since 2013. On the basis of the JRC cost curves for year 2020, specified in Ricardo Energy & Environment (2016), the cost of reaching a 17% CO_2 reduction is calculated for the three LCV segments.

For battery electric vehicles, as tailpipe CO_2 emissions are zero, cost curves describe the costs incurred to reduce their energy consumption to a given level. These costs include the additional costs for the batteries (at an assumed battery pack cost of 200 EUR/kWh), the electric motor and propulsion system and the costs for additional technologies to increase vehicle efficiency, deducting the cost of the conventional engine and transmission. It is assumed that eLCV configuration will be such that they achieve their minimum cost point. eLCV technology costs and energy consumption are thus set to be the minimum of the 2020 curves developed in the framework of the study by Krause et al. (2017).

Table 1 specifies the assumed costs of the baseline vehicle as well as technology costs for 2018 conventional LCVs and eLCVs. For eLCVs, battery capacities and ranges are specified too.

In the present analysis, it is assumed that vehicles depreciate over time, and only the cumulative depreciated part of all costs (base vehicle cost and technology costs) is counted as for each life year of the vehicle. The assumed development of residual value shares over vehicle lifetime is shown in Fig. 2. The present analysis has been carried out on an annual basis for a vehicle age of up to five years, which is considered to cover the typical planning horizon of fleet managers. For completeness, TCO after a useful vehicle lifetime of 15 years is given, as well.

For both LCVs and eLCVs, a mark-up of 11% is applied to costs, covering marketing and dealer costs, manufacturer profits etc., to transform costs into retail prices a vehicle buyer will face. An annual discount rate of 0.095 has been applied to reflect the lower weight of later payments. These settings were developed in the framework of the study by Ricardo Energy & Environment (2018).

b) Fuel and Energy Costs

Fuel and energy expenses of the different vehicle types and segments are based on the 2017 prices for diesel and electricity[1], with a price trajectory towards 2035, following the trends of the EU Reference Scenario 2016 (European Commission, 2016). The same annual discount rate of 0.095 has been applied to reflect the lower weight of later payments. The same activity patterns are assumed for conventional LCVs and eLCVs, based on the settings developed within the study Ricardo Energy & Environment (2018) and displayed in Fig. 3.

c) Maintenance Costs

Maintenance cost estimates for conventional and eLCVs of the different segments are based on the assumptions made in Ricardo Energy & Environment (2018), the same discount rate is applied as for the previous cost types.

All cost types are calculated on an annual, cumulative basis, i.e. summing up the overall previous life years. While a useful vehicle lifetime of 15 years is assumed, the focus is on the cost comparison after 5 life years, as LCVs are often employed by commercial owners with a shorter time horizon.

Finally, the role of incentives is explored by examining the role that existing incentives, such as purchase subsidies and tax reductions, play in the TCO balance of eLCVs. For this purpose, information on eLCV incentives in the six largest EU[2] countries in terms of population (MP6), i.e. for Germany (DE), France (FR), the United Kingdom (UK), Italy (IT), Spain (ES) and Poland (PL) has been collected from the European Automobile Manufacturers' Association (ACEA) tax guide 2019 (ACEA, 2019) and national sources, and the impact on the overall financial attractiveness of eLCVs in these countries when considering them in the vehicle's TCO is examined.

3.4. CO_2 and pollutant emission impact

Both the Benchmark and the eLCV scenario have been run in the JRC fleet impact model DIONE, described in the previous section, in order to assess the impact of LCV fleet electrification on CO_2 emissions and air pollutants. DIONE fuel consumption and emission calculation for combustion engine vehicles is based on COPERT 4 v.11 road transport emission inventory software. Emissions of a wide range of air pollutants can be calculated in DIONE, including nitrogen oxide (NO_x) and particulate matter (PM), which are of particular importance for local air quality and thus the focus of this paper. For eLCVs, tank-to-wheel CO_2 and air pollutant emissions have been set to zero. The simplifying assumption can be justified as this paper addresses tank-to-wheel emissions. Moreover, under the EU emission trading system (Directive 2003/87/EC, latest amendment: Directive (EU) 2018/410), all electricity produced on top of the cap needs to be zero carbon, or emissions need to be compensated for in other sectors, so that upstream emissions of electricity

[1] Based on Energy prices and costs in Europe, COM(2019)1.
[2] The analysis covers the 27 European Union Member States and the UK.

Table 1
Vehicle costs and eLCV battery capacities used for TCO calculations. Sources: Ricardo Energy & Environment (2016); Krause et al. (2017); own calculations based on the JRC DIONE cost model.

	Small LCVs	Medium LCVs	Large LCVs
Base vehicle cost 2013 (EUR)	14,797	19,626	30,641
Technology costs for 2018 conventional vehicles (EUR)	495	495	562
Technology costs for eLCVs (EUR)	3299	9804	15,256
eLCV battery capacity (kWh)	21.4	37.5	59.8
eLCV range (km)	200	280	300

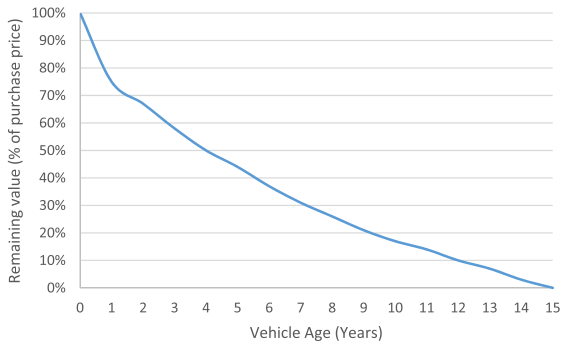

Fig. 2. Residual value (share of original purchase price) over vehicle lifetime.

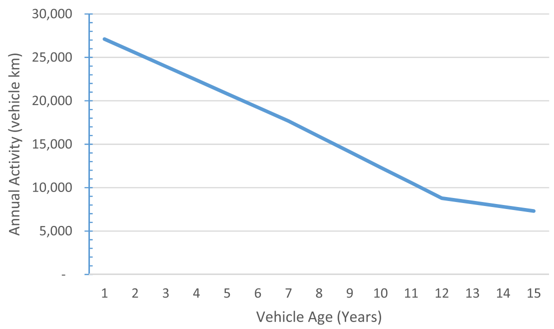

Fig. 3. Activity of LCVs (conventional and eLCVs) over vehicle age.

used in vehicles could be assumed to be zero. This approach is valid as a 'best case' estimate and has previously been employed in other model based studies, e.g. in Thiel et al. (2019, 2016b).

3.5. Air quality impact

For the air quality evaluation of the policies considered in this study, the SHERPA model has been used. The SHERPA model (Clappier et al., 2015; Pisoni et al., 2017; Thunis et al., 2016) mimics the behaviour of a full Chemical Transport Model (CTM, the 'state-of-the-art approach' in the field of air quality), using a 'meta-modelling' technique (that is to say, with a statistical representation of the full CTM model, simulating the same link between input and output of the original model). In other words, starting from input (emissions) and output (concentrations) of a set of simulation performed with a CTM (in this case CHIMERE, (Mailler et al., 2017)), SHERPA identifies and applies "bell-shaped" kernel functions to establish weighted, local regressions between input and output variables. After this step, SHERPA can be used as a 'surrogate' of the full CTM model.

From a more formal point of view, in SHERPA the concentration change ('delta' in comparison to the base case) in a receptor cell j is defined as the sum of the concentration changes due to changes in precursor emissions p emitted from any source cell i within the domain; the concentration delta in a receptor cell j can therefore be computed as follows:

$$\Delta C_j = \sum\nolimits_p^{N_{prec}} \sum\nolimits_i^{N_{grid}} a_{ij}^p \Delta E_i^p$$

where N_{grid} is the number of grid cells within the domain, N_{prec} is the number of precursors, ΔE_i^p and ΔC_j are the emission and concentration deltas, and a_{ij}^p are the unknown transfer coefficients between each source cell i and receptor cell j.

As said, in SHERPA, a_{ij}^{p} coefficients are assumed to be related through a bell-shaped function. This bell-shaped function accounts for the variation in terms of distance, as follows:

$$a_{ij}^{p} = \alpha_{j}^{p}(1 + d_{ij})^{-\omega_{j}^{p}}$$

where d_{ij} is the distance between a receptor cell j and a source cell i. The physical meaning of these two SHERPA parameters (α and ω) is quite important, as it defines the general behaviour of the model. The coefficient α can be interpreted as the relative importance of each precursor p in producing the pollutant concentration in cell j, whereas ω captures how the contribution of the precursor p emissions decreases with distance from cell j.

To be able to use SHERPA, the preliminary step is to estimate the coefficients α_{j}^{p} and ω_{j}^{p}. To do so, a least-square estimation approach has been applied starting from the results of a set of simulations performed with the CHIMERE model (see Pisoni et al. (2017) for more details) on the methodology applied to identify the coefficients and to validate the model. After this identification step, the model can then be used to evaluate the impact of policy scenarios, as done in this paper; in particular, to simulate the impact of emission reduction scenarios on $PM_{2.5}$, PM_{10} and nitrogen dioxide (NO_2) yearly average concentrations.

4. Future scenario assumptions

In order to quantify the impacts of a potential rapid uptake of eLCVs on CO_2 and air pollutant emissions in Europe, fleet composition scenarios need to be developed. Two scenarios, i.e. an ambitious "eLCV scenario", as well as a "Benchmark" scenario are developed and run in the JRC's fleet impact model DIONE.

In a first step, basic road vehicle fleet characteristics, i.e., vehicle stock, activities and energy efficiency trend of road vehicles are calibrated with the EU Reference scenario (European Commission, 2016). Then, the two scenarios for eLCV uptake are implemented, making the following assumptions:

- In the Benchmark scenario, eLCVs reach a market share of 30% by 2030, which is the benchmark level for low-emission vehicles specified in the EU's regulation for post-2020 CO_2 standards (Regulation (EU) 2019/631, see (European Union, 2019)).
- In the eLCV scenario, it is assumed that by 2030, all newly registered LCVs will be BEVs.

For both scenarios, the annual increase of eLCV sales shares until 2030 is linearised, starting from a 1% share. While this is a simplifying assumption and, in particular for the eLCV scenario an exponential trend in eLCV sales might be more realistic, it would be difficult to correctly predict their growth rate. Moreover, due to the slow turnover of stock, a lower rate in earlier years and then higher rate in later years could lead to approximately similar 2030 stock shares of eLCVs, which grow at a low but increasing rate under the present assumptions.

It is assumed that LCVs will be either conventional vehicles or eLCVs, i.e. no plug-in hybrids, range extenders or fuel cell vehicles are covered in this study. Finally, analysis is carried out on EU level in this step, using a unique eLCV new registration share as well as average vehicle replacement and survival rates. While there are differences in annual new registration rates of LCVs among EU member states, leading to a relatively faster or slower spread of new technologies, a simplified approach deemed justified as the main focus of this analysis was to assess the order of magnitude of impacts EU-wide.

The resulting composition of LCV stock over time, for the Benchmark and eLCV scenario, is shown in Fig. 4. In the Benchmark scenario, eLCVs reach a stock share of 10% by 2030, whereas in the eLCV scenario they make up for 34%.

The differences between these two scenarios constitute the basis for estimating the extent of reductions in CO_2 emissions and air pollutants through ambitious eLCV market uptake.

For the analysis of the current state of the market across the EU and the assessment of the previously defined future scenarios, the data collected at the previous steps are analysed: they are normalised according to the total vehicle fleet of each country, missing data gaps are completed through the appropriate intra/extrapolations using available data.

On the financial side, the TCO for eLCVs is analysed and complemented with information on subsidies and other support measures in different EU member states to assess the economic attractiveness.

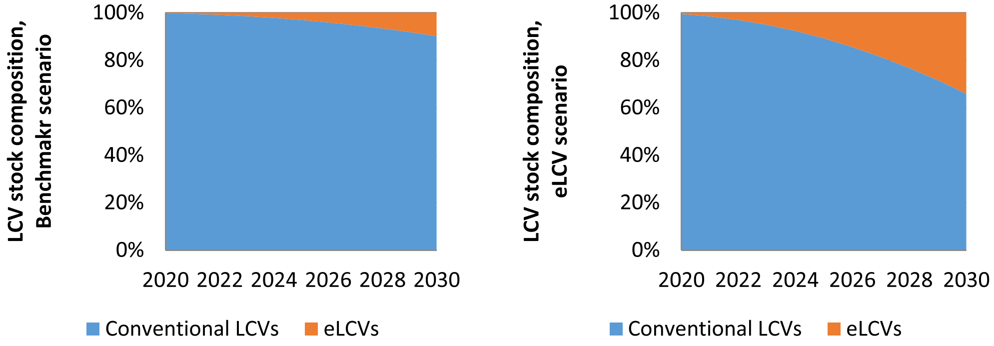

Fig. 4. LCV fleet composition for the Benchmark (left) and eLCV scenario (right).

On the environmental side, the fleet impact model DIONE is run to calculate CO_2 as well as air pollutant emissions of road transport under the Benchmark and the ambitious eLCV scenario. Developed and run at the European Commission's JRC (see Harrison et al., 2016; Thiel et al., 2016a, 2016b), DIONE is a road transport fleet projection tool that allows to analyse scenarios of road vehicle stock, activity, energy consumption and CO_2 as well as air pollutant emissions up to 2050. Air pollutant emission changes in Europe are further analysed within the SHERPA model. Moreover, all relevant visualisations are produced per selected indicator and scenario. The assessment results are used to formulate the outputs that measure the status of eLCVs, future prospects and potential for improvements.

5. Results of the analysis for current status and scenarios of eLCVs market uptake

This section presents the results of applying the methodology for Europe, covering the EU[2] member states.

5.1. Support measures to achieve policy goals and status of eLCV deployment in the EU

Since the literature suggests that the TCO is a critical factor in discouraging companies from purchasing eLCVs, this study focuses on the financial support measures with an influence on the TCO that can be quantified. More specifically, two types of acquisition incentives have been investigated, the purchase subsidies and the registration tax reduction, and one type of operational/recurring ownership incentive, the annual circulation tax reduction. These three classes of measures that were in place in 2018 in the MP6 have been identified. Regarding the purchase subsidies, three situations concerning the eLCV support have been observed: a positive situation (when the sum awarded for the purchase of an eLCV is superior to the one awarded to purchase an ePC (Spain, UK), a neutral situation (the two sums were equal – Germany, France, Poland), and a negative situation (when the sum for eLCVs was inferior – Italy).

On the current market uptake side, according to the data of EAFO, the eLCV category has an increasing presence in the EV market in 2010–2018, mainly because of their high potential use in commercial fleets. During this period, BEVs dominated this market segment and the EU eLCV fleet increased from 798 new registrations in 2010 to 20,313 in 2018, an increase of 2445% with most of the available models being based on vehicle architectures primarily developed for goods transport. In the first years, the alternative fuel (AF) LCV market was dominated by compressed natural gas (CNG) vehicles starting from a share of 1.5% compared to just 0.1% for BEVs.

A rapid decrease of the CNG share combined with a constantly increasing trend for the BEV market lead to 2014 being the break-even year after which BEVs surpass CNG registrations. Since 2014, the BEV market has been gaining momentum, increasing its shares ten times between 2010 and 2018, while CNG shares have been almost constant at the 0.4% levels. The AF LCV new registrations (including Battery Electric Vehicle – BEV, Fuel Cell Electric Vehicle – FCEV, Plug-in Hybrid Electric Vehicle – PHEV, Compressed Natural Gas – CNG and Liquefied Natural Gas – LNG vehicle figures) in the EU in 2010–2018 and their relevant shares are presented in Fig. 5.

For the TCO analysis, it was chosen to focus on the MP6, since they represent 70.71% of the EU population and 51.40% of the EU surface. Moreover, the same MP6 countries constitute the top six LCV and PC fleets in 2017, but at different positions. For the rest of the indicators (eLCV, eLCV/LCV, ePC and ePC/PC), there are other countries in the corresponding top six due to their advanced level of EV deployment (e.g. the Netherlands, Sweden, etc.). It should be noted that the MP6 contribution to EU eLCV fleet is 85.54% and the share eLCV/LCV is greater than the EU average one.

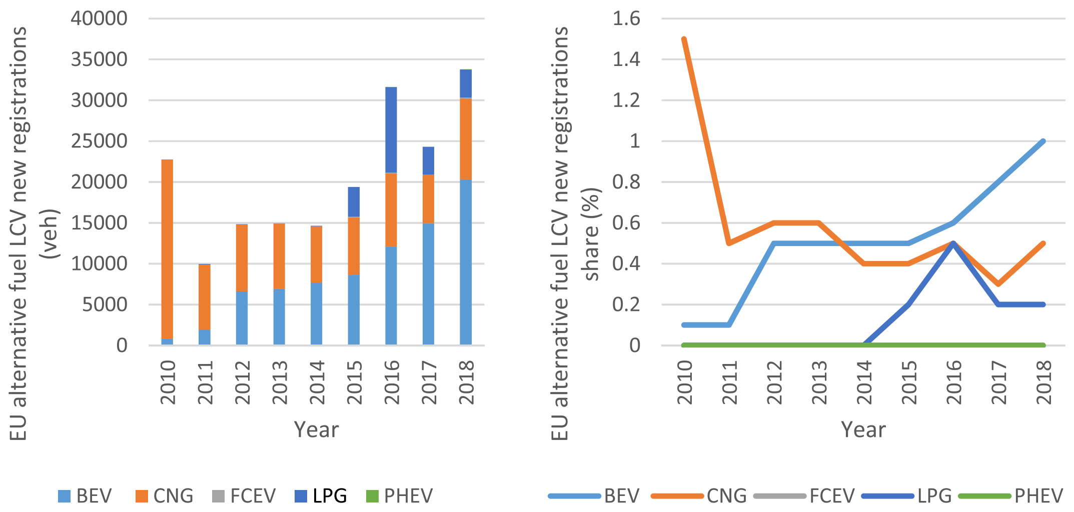

Fig. 5. Alternative fuel LCV new registrations in the EU between 2010 and 2018 (left) and relevant shares (right) (European Alternative Fuels Observatory, 2019).

Table 2
Characteristics of six most populated countries in EU in 2017.

Member State	Population	eLCV (rank)	LCV (rank)	eLCV/LCV	ePC	PC (rank)	ePC/PC
Germany	81,276,000	10,466 (2)	2,713,631 (5)	0.386%	117,984	46,474,594 (1)	0.253%
France	67,063,000	27,534 (1)	6,200,980 (1)	0.444%	116,479	32,005,986 (3)	0.364%
UK	65,081,000	4,134 (3)	3,892,041 (3)	0.106%	131,267	31,200,182 (4)	0.421%
Italy	60,963,000	2,069 (6)	3,502,654 (4)	0.059%	13,246	38,520,000 (2)	0.034%
Spain	46,335,000	2,958 (4)	4,585,923 (2)	0.065%	16,728	23,500,401 (5)	0.071%
Poland	38,494,000	34 (19)	2,574,312 (6)	0.001%	1,712	22,503,579 (6)	0.008%
Σ MP6 countries	359,212,000	47,195	23,469,541	0.201%	397,416	194,204,792	0.205%
EU	508,000,000	55,170	32,544,465	0.169%	650,571	263,183,211	0.247%
Σ MP6/EU	70.71%	85.54%	72.12%		61.09%	73.79%	

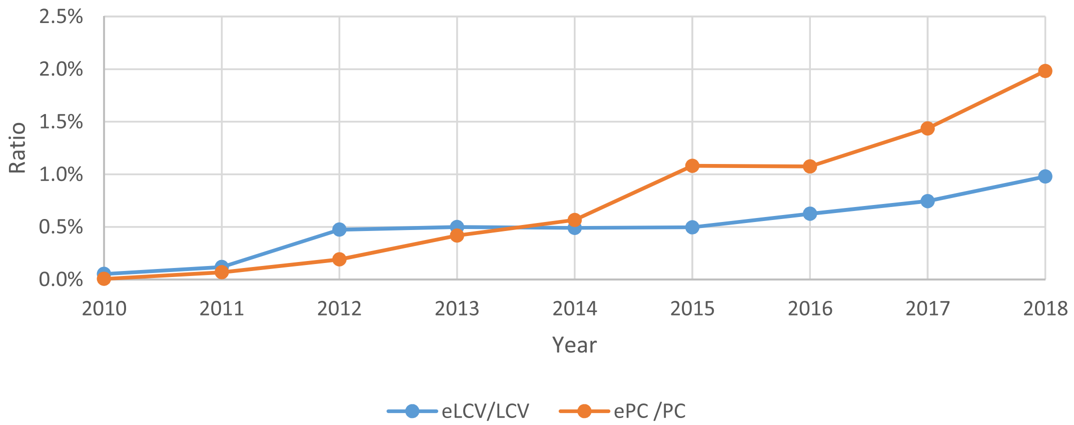

Fig. 6. The evolution of new registration shares of eLCVs and ePCs at EU level between 2010 and 2018 (European Alternative Fuels Observatory, 2019).

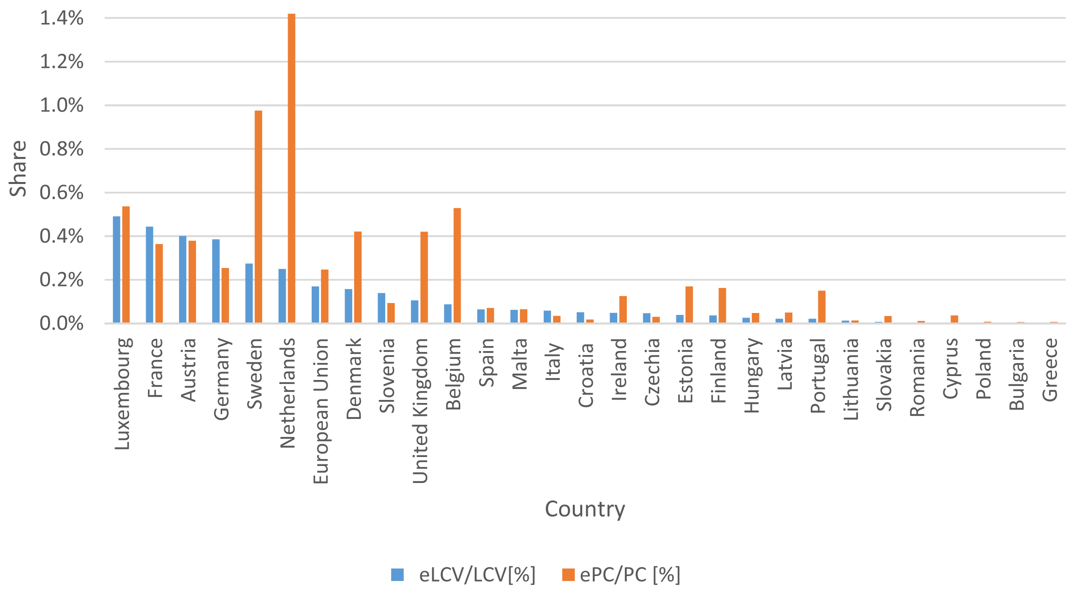

Fig. 7. Fleet shares for eLCV/LCV and ePC/PC for EU countries in 2017 (European Alternative Fuels Observatory, 2020; European Commission, 2019b; Eurostat, 2019).

Table 2 presents the data for Germany, France, UK, Italy, Spain and Poland, ordered by population number.

The EU evolution of the new registration shares of eLCVs and ePCs is presented in Fig. 6 for the period 2010–2018. Both evolution trends are normally rising but the increase of ePC share is more rapid in the last years.

With regards to the absolute numbers of eLCV new registrations at country level within the EU during the period 2010–2018,

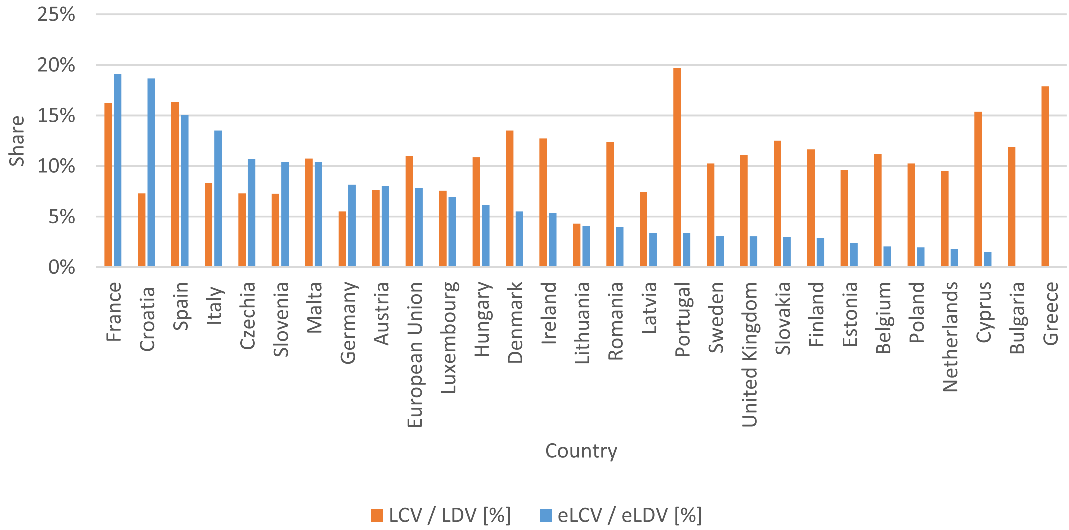

Fig. 8. The eLCV/eLDV fleet shares and LCV/LDV for EU countries in 2017 (European Alternative Fuels Observatory, 2020; European Commission, 2019b; Eurostat, 2019).

France has by far the biggest eLCV market with 40,542 new registrations in total for the analysis period, followed by Germany which accounts for just 15,337 new registrations. The UK, Spain and the Netherlands complete the top-5 countries in terms of eLCV registrations with 5356, 4759 and 3127 vehicles respectively. In terms of eLCV new registration shares in 2018, Germany leads with 1.93% and is followed by France (1.81%), Sweden (1.40%), the Netherlands (1.17%) and Luxembourg (1.08%).

Fig. 7 presents the shares of eLCVs and ePCs in the respective vehicle stocks for the EU countries in 2017, the data being ordered by decreasing share of eLCVs. Comparing the two shares, only France, Austria and Germany have the eLCV fleet share higher than the ePC fleet share.

To have a more complete understanding, it is useful to complement these results with the share of eLCVs in the total electric light duty vehicle (eLDV) fleet of each EU country in 2017 (see Fig. 8). It can be observed that France has the highest eLCV fleet share and a quite high LCV fleet share, which explains the significant absolute eLCV fleet values. Out of the MP6 focus group, France, Spain, Italy and Germany exceed the EU average value of eLCV fleet share from the total eLDV fleet.

Noteworthy is also the progress in vehicle manufacturing, which can be observed through the evolution of the product range.

The LCV segment has steadily progressed from a niche with only four different vehicle models registered in 2010, reaching forty-four in 2018, eleven times more, a fact linked to the provision of extended purchase options and availability from the vehicle manufacturers.

The eLCV market has been led by French manufacturers, beginning with Goupil and Citroen in 2010 and then continuing with Renault, which has been leading the market ever since with its Kangoo EV version, except in 2017. The French manufacturers have been introducing more models (e.g. Zoe Van) while other manufacturers entered the market but had a brief presence (e.g. Mia electric 2011–2013).

Since 2014 there is a clear increase in model range, a fact also coinciding with the eLCVs market shares surpassing those of the CNG LCV variants. Moreover, the Japanese manufacturers managed to be in the leading market ranks since 2014, while the almost constant absence of the traditional German vehicle manufacturers is also noteworthy, with the exception of the Vito E-cell that occupied one of the first places in 2012–2013 but behind the French manufacturers and the new entry model Work by the German company Streetscooter, owned by the German postal service.

5.2. Total cost of ownership results

This section presents the results from the analysis of cost of ownership of eLCVs, comparing them to conventional LCVs. On this basis, it then gives some insight into the level and role of present financial incentives. Table 3 summarises the cumulative vehicle and technology costs, energy costs and operational costs for both eLCVs and LCVs of small, medium and large size, and compares their costs over the first five vehicle life years as well as over a total vehicle lifetime of 15 years. For a description of the elements considered and the quantified inputs to the TCO calculations, see Section 4.3 on TCO analysis.

As it can be seen from Table 3, small eLCVs have modest additional technology costs compared to small conventional LCVs, and due to significantly lower energy costs and slightly lower operating costs, they break even in their second life year, as indicated by the negative values and green shading in the last column of the table. Over 15 years, small eLCVs save a total of 2600 EUR. Medium and large eLCVs, in contrast, do not break even with conventional LCVs. After five years, they have caused total additional costs of 1200 and 2300 EUR, respectively. Their fifteen-year balance is slightly more favourable, as fuel savings continue to accrue whereas initial investment into the more costly eLCVs are largely already written off. The depreciation trend, applied uniformly to eLCVs and

Table 3
TCO results and comparison of costs of conventional LCVs and eLCVs, all costs cumulative and in EUR.

Segment	Power-train	Vehicle Age	Base Vehicle Costs (cum.)	Techno-logy Costs (cum.)	Energy Costs (cum.)	Opera-ting Costs (cum.)	Total Vehicle Costs (cum.)	BEV Additional Cost over ICE
Small LCV	DSL ICE	1	4,106	124	1,520	1,410	7,160	
		2	5,306	160	2,870	2,698	11,034	
		3	6,539	197	4,038	3,874	14,648	
		4	7,540	227	5,045	4,948	17,760	
		5	8,225	248	5,908	5,928	20,310	
		15	11,597	350	9,492	12,086	33,525	
	BEV	1	4,106	825	951	1,287	7,169	9
		2	5,306	1,066	1,795	2,462	10,629	-404
		3	6,539	1,314	2,526	3,536	13,914	-734
		4	7,540	1,515	3,156	4,516	16,726	-1,034
		5	8,225	1,652	3,696	5,411	18,984	-1,326
		15	11,597	2,330	5,937	11,032	30,896	-2,629
Medium LCV	DSL ICE	1	5,446	124	1,932	1,825	9,326	
		2	7,038	160	3,647	3,492	14,336	
		3	8,673	197	5,132	5,014	19,016	
		4	10,000	227	6,412	6,404	23,043	
		5	10,910	248	7,509	7,673	26,339	
		15	15,382	349	12,063	15,644	43,438	
	BEV	1	5,446	2,451	1,222	1,662	10,781	1,454
		2	7,038	3,167	2,306	3,180	15,691	1,355
		3	8,673	3,903	3,245	4,566	20,388	1,372
		4	10,000	4,501	4,055	5,832	24,387	1,345
		5	10,910	4,910	4,749	6,988	27,556	1,217
		15	15,382	6,922	7,629	14,246	44,179	741
Large LCV	DSL ICE	1	8,503	141	2,916	2,771	14,330	
		2	10,988	182	5,506	5,302	21,977	
		3	13,541	224	7,747	7,613	29,125	
		4	15,613	258	9,679	9,723	35,274	
		5	17,033	282	11,336	11,651	40,301	
		15	24,015	397	18,211	23,753	66,376	
	BEV	1	8,503	3,814	1,884	2,516	16,717	2,387
		2	10,988	4,929	3,558	4,814	24,288	2,311
		3	13,541	6,074	5,006	6,912	31,533	2,408
		4	15,613	7,003	6,255	8,828	37,699	2,426
		5	17,033	7,640	7,325	10,578	42,576	2,275
		15	24,015	10,772	11,768	21,567	68,121	1,745

Abbreviations: DSL ICE – Diesel Internal Combustion Engine, BEV – Battery Electric Vehicle.

Table 4
Financial incentives for the eLCV versions of Renault Kangoo and Nissan NV200, and taxes in the six most populated EU member states.

	Purchase incentives, one-time	Acquisition /registration taxes, one-time	Ownership taxes, annual
DE	Kangoo Z.E.: 5,000 EUR private, 3,000 EUR company Nissan e-NV200: 5,000 EUR private, 3,000 EUR company	–	For Kangoo Z.E. years 1-10: 0 EUR For Kangoo Express: 164 EUR For Nissan e-NV200 years 1-10: 0 EUR For Nissan NV200: 180 EUR
FR	Kangoo Z.E.: 6,000 EUR Nissan e-NV200: 6,000 EUR	Kangoo Z.E.: 0 EUR Kangoo Express: 258 EUR Nissan e-NV200: 0 EUR Nissan NV200: 288 EUR	–
UK	Kangoo Z.E.: 6,000 EUR Nissan e-NV200: 6,391 EUR	Kangoo Z.E.: 0 EUR For Kangoo Express: 192 EUR For Nissan e-NV200: 0 EUR For Nissan NV200: 594 EUR	Kangoo Z.E.: 0 EUR Kangoo Express: 270 EUR Nissan e-NV200: 0 EUR Nissan NV200: 270 EUR
IT		–	Kangoo Z.E. years 1-5: 0 EUR, years 6-15: 14 EUR Kangoo Express: ca. 55 EUR Nissan e-NV200 years 1-5: 0 EUR, years 6-15: 25 EUR Nissan NV200: ca. 100 EUR
ES	Kangoo Z.E.: 6,000 EUR Nissan e-NV200: 6,000 EUR	Kangoo Z.E.: 0 EUR Kangoo Express: 770 EUR Nissan e-NV200: 0 EUR Nissan NV200: 1,400 EUR	Kangoo Z.E.: ca. 20 EUR or more Kangoo Express: ca. 80 EUR or more Nissan e-NV200: ca. 20 EUR or more Nissan NV200: ca. 80 EUR or more
PL	–	–	–

Incentives and taxes for EVs (blue) and conventional vehicles (black).

Table 5
Financial differences between the eLCV and LCV variants of the Renault Kangoo and Nissan NV200, for a 5-year time horizon, from a company perspective.

		5-year TCO difference	eLCV purchase subsidy	Acquisition/ registration tax difference	5-year ownership tax difference	Sum of incentives	Total difference
DE	Kangoo	-1,326	-3,000	0	-690	-3,690	-5,016
	NV200	1,217	-3,000	0	-757	-3,757	-2,540
FR	Kangoo	-1,326	-6,000	-258	0	-6,258	-7,584
	NV200	1,217	-6,000	-288	0	-6,288	-5,071
UK	Kangoo	-1,326	-6,000	-192	-1,135	-7,327	-8,653
	NV200	1,217	-6,391	-594	-1,135	-8,120	-6,903
IT	Kangoo	-1,326	0	0	-231	-231	-1,557
	NV200	1,217	0	0	-420	-420	797
ES	Kangoo	-1,326	-6,000	-770	-252	-7,022	-8,348
	NV200	1,217	-6,000	-1,400	-252	-7,652	-6,435
PL	Kangoo	-1,326	0	0	0	0	-1,326
	NV200	1,217	0	0	0	0	1,217

conventional LCVs, supposes that in the fifth life year, the vehicle retains a residual value of 44% of its initial value and reaches a residual value of zero only after 15 life years. Assuming that, from an operators' perspective, the vehicle is fully written off earlier, typically after five to nine life years with zero residual values in terms of book-keeping, it would deteriorate the competitive position of eLCVs compared to conventional LCVs, as their total upfront higher technology costs are confronted with fuel savings over a more limited time period.

Further elements that need to be considered in a complete cost of ownership analysis are the taxes applied to different vehicles, as well as potential purchase premia offered presently in different EU member states to foster electric vehicle market penetration. Such benefits often depend on vehicle characteristics such as weight, price or segment, and a full summary of all conditions in the EU is beyond the scope of this paper. Instead, a specific comparison has been carried out for two eLCVs, namely the Renault Kangoo Z.E. and the Nissan eNV200. These two have been chosen on the basis of their large market penetration, due to the fact that they have a clear conventional counterpart vehicle to compare with (the Kangoo Express and the Nissan NV200), and that they cover two different market segments. The Kangoo has been assigned to the small LCV category, based on the weight of the conventional version of 1410 kg, and the NV200 to the medium segment, as its conventional version weighs 2000 kg.

Table 4 summarises purchase incentives for the eLCV versions in the first column, and quantifies the acquisition or registration taxes, as well as annual ownership taxes, for the BEV and conventional versions in the second and third column respectively. This information has been gathered for the six EU member states with the largest population i.e. Germany, France, UK, Italy, Spain and Poland. Favourable company vehicle taxation is another incentive available in different member states, but has not been included in the analysis due to difficulties in accessing the legal texts and interpreting complex and diverse national legislation.

To include member state incentives into the cost of ownership calculations, eLCV purchase subsidies as well as acquisition tax benefit differences need to be considered as one-time benefits, whereas annual ownership tax benefits need to be discounted and

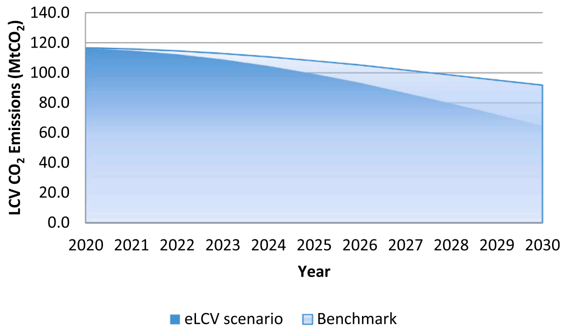

Fig. 9. LCV CO_2 emission development over time ($MtCO_2$), for Benchmark and eLCV scenario.

aggregated over time.

Table 5 presents the respective benefits for the six MSs (in EUR), over a five-year period, from a company perspective, adds them to the 5-year TCO results presented earlier, and shows the total results. The first column covers their TCO, the following three columns present subsidies for eLCVs and tax differences. Negative values (green cells) indicate lower costs for the eLCVs in comparison to LCVs.

As it can be seen, out of the six MSs, just one does not presently offer any incentives for eLCV market introduction. The sum of incentives in the remaining five MSs range from around 700 EUR over five years in Italy to up to 8000 EUR in the UK. In the UK, France and Germany, total incentives are high enough to make the medium eLCV financially more attractive than its conventional counterpart. The small eLCV is more beneficial even in the absence of financial measures, as demonstrated by the TCO comparison, therefore any incentives come as an extra financial benefit.

In sum, in many cases small and medium eLCVs are already financially more attractive than their conventional counterparts under present conditions, from a five-year perspective. Their sluggish market uptake therefore points to other potential barriers, such as lack of information, lack of models, or range considerations and recharging infrastructure potentially limiting their attractiveness. The TCO assessment assumes a residual value of LCVs of 44% after life year 5. It is presently unclear whether this is a realistic assumption for eLCVs, or if e.g. battery degradation might make them lose value more rapidly. In general, the assumed vehicle lifetime of 15 years may not be realistic from a business point of view, where the investment is typically written off in fewer years.

5.3. CO_2 and air pollutant emissions

In both scenarios, emissions decline over time, which is due mainly to the increasing electrification in both scenarios, as well as a slight increase in conventional LCV efficiency, whereas total activity in terms of total LCV kilometres is projected to increase by 12% between 2020 and 2030, based on the EU Reference scenario 2016. By 2030, in the eLCV scenario, LCV CO_2 emissions decrease to 65 $MtCO_2$, which is a 30% or 27 Mt decrease compared to the benchmark. As LCVs make up for roughly 13% for total road transport CO_2 emissions, this translates into a 3.2% reduction of total 2030 road transport CO_2 emissions compared to the Benchmark scenario. Fig. 9 shows the development of CO_2 emissions for both scenarios over time.

With regards to air pollutants, Fig. 10 shows the development of NO_x and PM emissions under the eLCV scenario in terms of percentage of Benchmark scenario emissions. On an EU average, in 2030 PM emissions from eLCVs are 7% lower under the eLCV scenario than under the Benchmark scenario, and NO_x emissions are 22% lower. Compared to total road transport emissions, the 2030 differences are 3% for PM, and 5% for NO_x. Differences in how pollutant emissions are impacted by fleet electrification stem from differences in the emissions of the conventional vehicles that leave the fleet and are replaced by new BEVs.

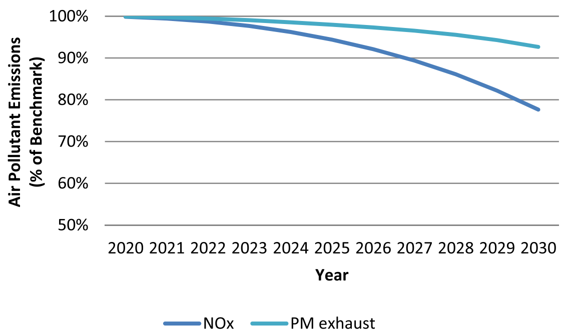

Fig. 10. Air pollutant emissions for the eLCV scenario compared to the Benchmark scenario.

Table 6
Air pollutant emission differences from total road transport, eLCV scenario versus Benchmark scenario.

	2025	2030
NO_x	−1.2%	−4.8%
NMVOC	−0.7%	−2.8%
NH_3	−0.6%	−2.5%
PM exhaust	−0.9%	−3.1%

5.4. Air quality impact analysis

As air pollutant emissions can have a detrimental impact on health, it is of particular importance how their regional and local concentration varies. To assess these concentrations, outputs from the DIONE model can be further processed in the surrogate air quality model SHERPA, which produces air pollutant concentrations per modelled grid cell at a 7 × 7 km resolution. Further details on the approach and previous applications are described in Gómez Vilchez et al. (2019) and Thiel et al. (2019).

In the present study, 2030 total road transport air pollutant emission differences for the eLCV scenario compared to the Benchmark scenario, as contained in Table 6 (NO_x, Non-Methane Volatile Organic Compounds – NMVOC, Ammonia – NH_3, PM), were introduced in the SHERPA model.

While the fleet impact calculations in DIONE were run at EU level, for assessing air quality impact it is relevant to consider the geographic distribution of emissions. Shares of total 2030 air pollutant emission reductions were therefore assigned to the different EU MSs based on their share of LCV activity. These reductions were divided by Benchmark scenario MS air pollutant emissions (sub split from total 2030 air pollutant emissions proportionally to MSs CO_2 emission shares in 2030, available from the EU Reference

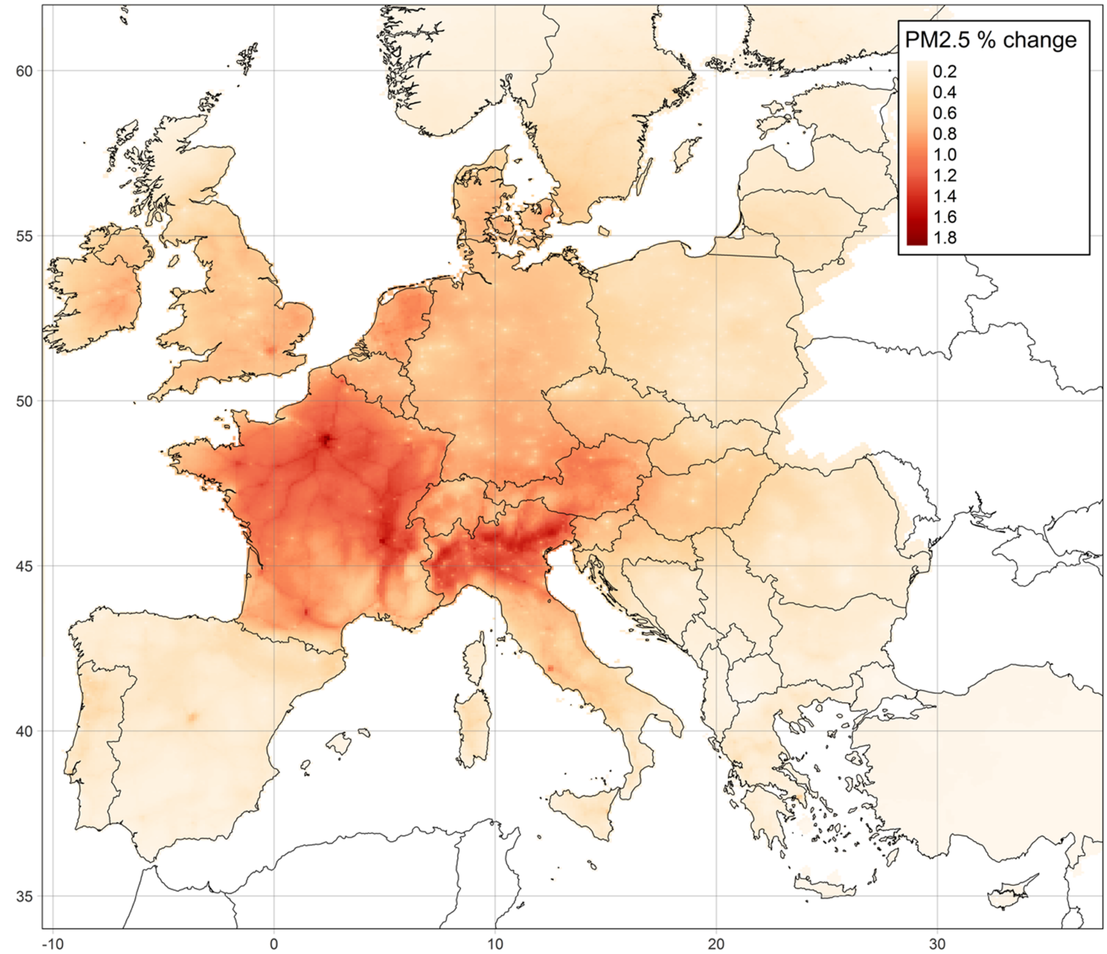

Fig. 11. Air quality impact due to the partial fleet electrification ($PM_{2.5}$ yearly average percentage reduction in 2030 of the eLCV scenario in comparison to the Benchmark scenario).

scenario). The resulting MS specific air pollutant reductions reflect the relative importance of LCV activity in the respective member states, with LCV air pollutant emission reductions of member states ranging from 35% (Luxembourg) to 175% (Denmark) of EU average emission reductions. Of the six countries considered in the TCO analysis, Spain, Germany and Poland exhibit lower than average benefits from LCV electrification, and UK, Italy and France higher ones, based on LCV activity in these MS. It is important to note that the SHERPA results presented below reflect this activity-based weighting, but do not mirror MS specific vehicle replacement patterns, which can be expected to play a significant role in fleet technology transition and should be investigated further.

The MS specific emission reductions, applied in the SHERPA model result in the percentage change concentrations of $PM_{2.5}$ presented in Fig. 11. The assumption is that eLCVs are deployed uniformly to the transport sector across each MS.

The percentage concentration changes go up to about 1.9%, and are especially relevant in northern Italy, across France, the Netherlands and Austria. Indeed the reductions of yearly average concentrations are quite small for $PM_{2.5}$: a) partly because of the fact that electrification involves only part of the total fleet, in the considered scenario; and b) partly because of the secondary nature of $PM_{2.5}$ concentrations, that heavily depend on other sources (residential sector, industry, agriculture, etc.).

6. Conclusions

Light commercial vehicles have been receiving much less public attention compared to passenger cars. This paper reveals that the eLCV market has shown strong and steady growth during the past years.

There is a clear Japanese/French domination of the market and a small group of models gathering by far the majority of consumers' choice, a fact clearly in line with the mass eLCV uptake observed in France.

As the calculations for the EU in this paper have shown, an ambitious electrification strategy could decrease CO_2 emissions from LCVs by 30% by 2030, which is a total road transport emission reduction by roughly 3%. Total road transport emissions of air pollutants would decline as well, e.g. NO_x by nearly 5%, and PM by ca. 3% on an EU average. Local concentration of $PM_{2.5}$ is reduced by up to just below 2% when distributing emission reductions evenly within member states, but impacts on city air quality could be stronger due to higher LCV activity. This effect merits further investigation.

The spike in demand of e-commerce- and home-delivery related last mile transport that has been observed during the recent SARS-CoV-2 outbreak could imply that the future scenarios for LCV transport demand used in this study are conservative if these consumer patterns are sustained after the end of the outbreak.

In sum, LCVs can make a contribution to CO_2 emission reduction and air quality improvement within the 2030 timeframe, and even more so in the future, given the slow turnover rates of vehicle fleets. For this to happen, a rapid increase of their market shares is needed. The present analysis of costs of ownership has shown that small eLCVs are already cost-competitive with their conventional counterparts today, while medium and large eLCVs have a slightly higher cost of ownership of 1200 and 2300 EUR over a period of five years, a gap which is fully covered by financial incentives in many member states.

This contrasts with the still small, albeit increasing, market shares of eLCVs, as shown in this paper. Apparently, a number of market barriers may be responsible. On the financial side, it is possible that the depreciation patterns assumed in this study do not match the buyers' perspective, due to too little experience with battery life and durability, and second hand market prices for eLCVs. This gap could be covered by information collection and distribution, and possibly by initial financial incentives for eLCVs and other zero emission options or higher taxes for polluting vehicles until a second hand market establishes. Secondly, non-financial market barriers could hamper the present uptake of eLCVs: be it that ranges of eLCVs are, in fact or according to the perception of buyers, inadequate for the given use patterns, or the recharging infrastructure is not yet fully deployed; be it that eLCV model choice, though increasing, does not yet fully cover clients' needs. Incentives, as well as infrastructure support, thus seem justified initially to help establish a market and reduce uncertainty. Last but not least, as eLCVs differ from ePCs in terms of vehicle type, operational requirements and buyers' choice criteria, developing policy measures and appropriate regulation for eLCVs seems to be necessary. One example for such need refers to the weight limits imposed on EU category B driving licenses, which might exclude the use of larger eLCVs carrying more battery weight under standard licenses and such weight limits should be reconsidered.

Fiscal incentives and support measures stimulating EV demand in the EU MSs need to be harmonised to avoid market fragmentation and promote more EVs EU-wide on the road. A well-designed and carefully tailored fiscal and regulatory framework would be beneficial.

It should be noted that there are also similarities between LCVs and PCs, as many of the available models are based on vehicle architectures that enable PC and LCV versions. For the case of eLCVs and ePCs this has obvious advantages for recharging infrastructure compatibility. More publicly accessible recharging points can also have a favourable effect on the deployment of eLCVs.

Further R&I efforts are needed in the field of transport electrification with a potential impact on the LCV segment in order to improve eLCV performance and reduce the TCO.

Further investment on the LCV segment by the European car manufacturers would have a positive effect in mass eLCV uptake, since they are leading global players in LDV and industries and their respective supply chains. In conclusion, eLCVs have a very big potential in Europe and can significantly contribute to the reduction of transport emissions and dependence on fossil oil based fuels. In combination with increased e-commerce and home-delivery, eLCVs could indeed turn out to evolve into an electro-mobility giant. In this context it may be useful to perform future studies for scenarios beyond 2030 with 100% eLCV stock.

CRediT authorship contribution statement

Anastasios Tsakalidis: Conceptualization, Methodology, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing, Supervision. **Jette Krause:** Methodology, Software, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing. **Andreea Julea:** Methodology, Software, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing. **Emanuela Peduzzi:** Methodology, Software, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing. **Enrico Pisoni:** Methodology, Software, Data curation, Writing - original draft, Visualization, Investigation, Writing - review & editing. **Christian Thiel:** Conceptualization, Methodology, Writing - original draft, Investigation, Writing - review & editing, Supervision.

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Glossary

ACEA: European Automobile Manufacturers' Association
AF: Alternative Fuel
BEV: Battery Electric Vehicle
CO_2*:* Carbon Dioxide
GHG: Greenhouse Gas
CNG: Compressed Natural Gas
CTM: Chemical Transport Model
DE: Germany
DSL: Diesel
EAFO: European Alternative Fuels Observatory
EC: European Commission
EEA: European Environment Agency
eLCV: Electric Light Commercial Vehicle
eLDV: Electric Light Duty Vehicle
ePC: Electric Passenger Car
ES: Spain
EU: European Union

EV: Electric Vehicle
FCEV: Fuel Cell Electric Vehicle
FR: France
FREVUE: Freight Electric Vehicles in Urban Europe
GHG: Greenhouse Gas
GPS: Global Positioning System
ICE: Internal Combustion Engine
IT: Italy
JRC: Joint Research Centre
LCV: Light Commercial Vehicle
LDV: Light Duty Vehicle
LPG: Liquefied Petroleum Gas
M1: Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.
MP6: Six largest European Union countries in terms of population
MS: Member State
N1: Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes.
NH_3: Ammonia
NMVOC: Non-Methane Volatile Organic Compound
NO_2: Nitrogen Dioxide
NO_x: Nitrogen Oxide
PC: Passenger Car
PHEV: Plug-in Hybrid Electric Vehicle
PL: Poland
PM: Particulate Matter
$PM_{2.5}$: Particulate Matter (with diameters of 2.5 μm and smaller)
PM_{10}: Particulate Matter (with diameters of 10 μm and smaller)
R&I: Research and Innovation
SET: Strategic Energy Technology
STRIA: Strategic Transport Research and Innovation Agenda
TCO: Total Cost of Ownership
TRIMIS: Transport Research and Innovation Monitoring and Information System
UNECE: United Nations Economic Commission for Europe
UK: United Kingdom
US: United States