# POLITECNICO DI TORINO

MSc Degree in Automotive Engineering

Master Thesis

# $CO_2$ Emission Reduction Challenge for Light Commercial Vehicles (LCVs) Beyond 2020

## The European LCV market assessment through $CO_2$ regulations with technical, economic and social analysis


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To my parents

## Sommario

Al fine di perseguire l'obiettivo "climaticamente neutra" previsto fino al 2050, il Parlamento europeo e il Consiglio hanno introdotto standards di prestazione delle emissioni di CO2 per ogni nuovo veicolo commerciale leggero (LCV) immatricolato nell'UE, compresi gli obiettivi dal 2020 in poi. Il presente lavoro è stato svolto in collaborazione con FCA-TOFAS company e rappresenta un contributo volto all'analisi di mercato per veicoli commerciali leggeri riguardante gli standards europei di emissione di CO2 nel periodo tra il 2020 e il 2030. Tale analisi di mercato sull'emissione di CO2 tiene conto degli importanti segmenti industriali tra cui i tipi di veicoli, i produttori, i parametri tecnici chiave e i driver principali nel mercato dei veicoli commerciali leggeri. Nella seconda parte vengono esaminati diversi fattori e le loro influenze sul mercato dei furgoni con l'analisi PEST al fine di riflettere meglio i cambiamenti del macroambiente. Per tale ragione, viene valutata una composizione della flotta con veicoli commerciali leggeri selezionati per ciascun segmento sulla base dei limiti di emissioni di CO2 a partire dal 2020. Le opzioni tecnologiche di ibridi (micro e lievi), ibridi plug-in, estensori di gamma e veicoli elettrici a batteria sono implementate sui segmenti LCV al fine di rispettare determinati obiettivi di emissione di CO2 su diverse composizioni di flotte e scenari tecnologici, utilizzando gli studi e le documentazioni della Commissione europea a supporto delle valutazioni politiche delle normative sul CO2 per auto e furgoni post-2020. Successivamente, vengono eseguite analisi finanziarie che riassumono la redditività degli scenari politici dal punto di vista del produttore e l'analisi del costo totale di proprietà con periodi di rimborso per il cliente al fine di valutare gli impatti delle modifiche quantificabili con le analisi di sensibilità. In conclusione, in base ai risultati delle analisi, viene fornita una tabella di marcia per gli anni successivi al 2020.

# Abstract

As a part of the European Union's objective of being climate neutral by 2050, the European Parliament and the Council introduced CO2 emission performance standards for each new light commercial vehicle (LCV) registered in the EU including targets from 2020 onwards. This study is executed in collaboration with FCA-TOFAS Company and attempts to analyze the future evolution of LCVs according to the EU emission standards by taking into consideration economic, social and technical factors between 2020 and 2030. In this context, market analysis is carried out to provide a general overview of important industry segments including vehicle types, manufacturers, key technical parameters and main drivers in the LCV market in the beginning. Several factors and their influences on the vans market are examined with PEST analysis in order to better reflect the changes of macro-environment in the second part of the thesis. Then, a fleet composition with selected LCVs for each segment is evaluated on the basis of CO2 emission limits starting from 2020. Technology options of hybrids (micro and mild), Plug-in hybrids, Range extenders and battery electric vehicles are implemented on LCV segments in order to comply with determined CO2 emission targets over different fleet compositions and technology scenarios by using the European Commission studies and documentations supporting the policy assessments of the post-2020 cars and vans CO2 regulations. Afterwards, financial analysis which summarizes the profitability of policy scenarios from manufacturer's point of view and total cost of ownership analysis with payback periods for customers are performed to evaluate the impacts of quantifiable modifications with sensitivity analysis. In conclusion, a roadmap beyond 2020 is provided depending on the results of analysis.

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# 1 INTRODUCTION

Today, greenhouse gas emissions coming from the light duty vehicles contribute almost a quarter of EU's total emissions of CO2 so the European Parliament and the Council introduced two ambitious targets on new CO2 emission performance standards for newly registered passenger cars and light commercial vehicles (LCVs) in the EU from 2020 onwards in order to limit the effects of global climate change regarding to the Paris agreement and to encourage EU automotive manufacturers the production of more eco-friendly and fuel-efficient low- and zero- emission vehicles. The main aim of the thesis is to determine the optimal trade-off between the fleet composition scenarios composed of different LCVs segments, cost types and alternative powertrains based on these new EU CO2 emission targets for the years of 2025 and 2030 by taking into account market evolutions, economic transformations and technical constraints from the perspective of LCVs' manufacturer as well as consumer with total cost of ownership (TCO) analysis.

For this purpose, this study is focused on the history of LCVs in order to comprehend LCV types and characteristics, main drivers and restraints, potential powertrain technologies that allow CO2 emissions reduction and fuel savings with market analysis in the first part. Then, PEST analysis on current competitive LCV market situation in Europe in terms of binding CO2 regulations is carried out to better understand EU legislations setting on CO2 emission level for EU vans manufacturers, low emission zone regulations created by local governments in city centers, benefits and incentives for alternative drivetrains provided by EU countries, critical considerations of LCV's buyer and technical advancements in the industry by analyzing political, economic, social and technological factors in the next section.

Afterwards, in order to assess the techno-economic impacts of LCV future evolutions with different technology options, powertrain and cost types, CO2 emission reduction cost curves developed by Ricardo Energy & Environment and Joint Research Center (JRC) for EU Commission's CO2 emission legislations for 2020 onwards for light commercial vehicles (DIONE Model cost curves) based on WLTP in percentage are used for selected vans excluding eco-innovation technologies. As the cost curves are based on 2013 baseline vehicles, a selected average manufacturer fleet composition is created from market shares, NEDC CO2 emission values and mass in running orders of four different LCV segments by separating them into three classes, taking into account data published on European Environment Agency. However, market shares that are determined for the period between 2013 and 2019 for each class are predicted to be used in the further analysis beyond 2020. Also, NEDC CO2 emissions in the fleet composition are translated into WLTP CO2 emissions with ratios depending on powertrain types by using JRC study in consequence of new European CO2 targets are calculated based on the WLTP values starting from 2020/2021. Therefore, four different CO2 emission targets with average annual reduction rates are quantified based on the WLTP-based relative reduction from 2021 on in order to assess the fleet composition developments that are considered with different powertrain technology scenarios by taking into account their mass corrections. Also, total cost of ownership analysis is performed for each LCVs powertrain type and segment by indicating payback periods over the 15-year lifetime of LCVs, including additional manufacturing costs, fuel and energy costs and operation and maintenance costs with fiscal incentives to reflect the perspective of the end-user. In conclusion, various policy options are discussed to identify possible roadmaps in the future LCV market according to the perspective of the company and customer by taking into consideration sensitivity analysis carried out on the basis of various assumptions of the TCO model and political, economic, social and technological factors as explained previously.

# 2 LIGHT COMMERCIAL VEHICLES

## 2.1 Definition

Light commercial vehicles (LCVs), as they can be called 'vans', are defined as vehicle groups with a variety of shape and size which can carry goods and have a gross weight less than 3,5 metric tons (N1 category) in European Union. They can be classified in three categories based on reference mass:

Class I, represents the vans with a reference mass up to 1305 kg,

Class II, vehicles have reference mass between 1305 and 1760 kg,

Class III, LCVs having a reference mass exceeding 1760 kg are considered in N1 category [1].

## 2.2 LCV Segments

On the other hand, LCVs category can be divided, depending on the variety range of vehicle characteristics and configurations such as versatility, payload, interior space and volume, in four sub-segments:

Car-derived van is a light commercial vehicle which is derived from a passenger vehicle and which has a maximum laden weight until 2 tons (Fiat Panda, Ford Fiesta Van and Vauxhall Corsa)

Small size van can have a typical payload between 500-900 kg and average 1,7 meters length (Fiat Fiorino, Mercedes Citan and Dacia Dokker)

Compact size van is able to carry a greater load than small size van and their dimensions are similar to B-segment passenger cars (Fiat Doblo, VW Caddy and Renault Kangoo)

Midsize van offers more payload, height and load space with their medium size (Fiat Talento, Mercedes Vito and Ford Transit Custom)

Large size van has payload between 1200 and 1500 kg with higher volume and ability of carrying more goods (Fiat Ducato, Iveco Daily and Nissan NV400)

Pick-up van is defined as a vehicle carrying goods with an open back loading area (Fiat Fullback, Ford Ranger, Toyota Hilux)

## 2.3 Characteristics of the light commercial vehicle market

Unlike the passenger cars market where the main customer target is to transport the fewer number of people, there are different customer profiles with diversified requirements depending on mileage, goods to be carried or technical constraints in LCV market so that customers are generally dealers, professional users, fleet managers or companies with having a wide range of vehicle fleets. Their needs are varying based on following issues:

- Light commercial vehicle market is a “Business-to-business” market so that as the process is more complex and buying process is longer with respect to Business-to-consumer market, commercial customers and salespeople are more sophisticated persons with technical and engineering background to manage strategic financial investments such as decisions to purchase or lease a van and for the rapidity of the supply that purchasing activities are completed through digital platforms between companies. Fleet owners focus on more specific issues such as technical parameters of the vehicles, safety, punctuality, insurance and maintenance cost so that a high degree of customization is needed [2].
- Since there is no particular license as a requirement to drive an LCV, it is easy to purchase and operate it and they are served to provide service in such industries as manufacturing, transport, storage etc. The report published by Society of Motor Manufacturers & Traders (SMMT) monitors the LCV’s role in the UK’s industry with users depending on their work as shown in the figure. It is obvious that construction is the widest industry that contributes to the UK’s economy by far with almost 1 million vans in 2017, followed by whole, retail and repair of motor vehicles; manufacturing; and transport storage accounting for nearly 38% of the whole LCV parc [3].

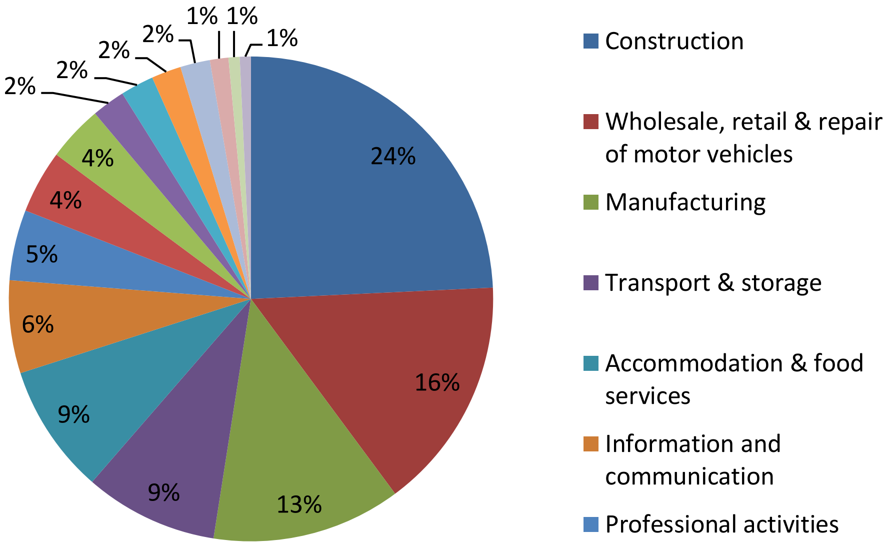



**Figure 1 - LCV Usage by Industry Segment in UK**

- Usage profiles of different type of vehicles are important to understand the impact of mileage on the cost effectiveness of the light commercial vehicle as because depending on the size and powertrain type of the vehicle or journey for business within a country or inner-city, total cost of vehicle can increase gradually so that fleet operators or companies generally decide on which LCV type could be the best suited choice for their fleets by analyzing how varies annual and lifetime mileage of a vehicle. [4]
- Vehicles in a fleet need periodically to go to vehicle maintenance service so that in order to increase the uptime of fleet and improve the efficiency, customers in some sectors prefer to invest their own maintenance workshop or, for an example, manufacturers offer home or depot charging hardware installation in case of existing electrified vans in their own fleet [2].
- Second hand markets of LCVs are important for small enterprises and sole traders to organize their transportation business on a tight budget while for the medium and large businesses using the same vehicles in the long term is essential for maintaining the productivity [2].

## 2.4 Main players in the Commercial vehicle market

As light commercial vehicles can be classified in different ways according to reference mass, payloads, volume or other characteristics, also OEMs can be defined depending on the product portfolios within their fleets ,as light, medium and heavy fleet manufacturers. [5] The distinction is made between the manufacturers based on each segment as described above by taking into account the new LCV registrations (provisional) for each manufacturer in 2019. [6] Among the van makers, Fiat and Renault have the lighter LCVs in their product portfolio with respect to other OEMs like VW and Ford that majority of their fleets formed by larger vans like Volkswagen Transporter-Crafter and Ford Transit Custom-Transit respectively while Daimler and Iveco have focused on producing heavier vans for the mass-market. Also, Iveco, Daimler and Renault have been carrying on their commercial vehicle business in all categories by manufacturing medium and heavy lorries.

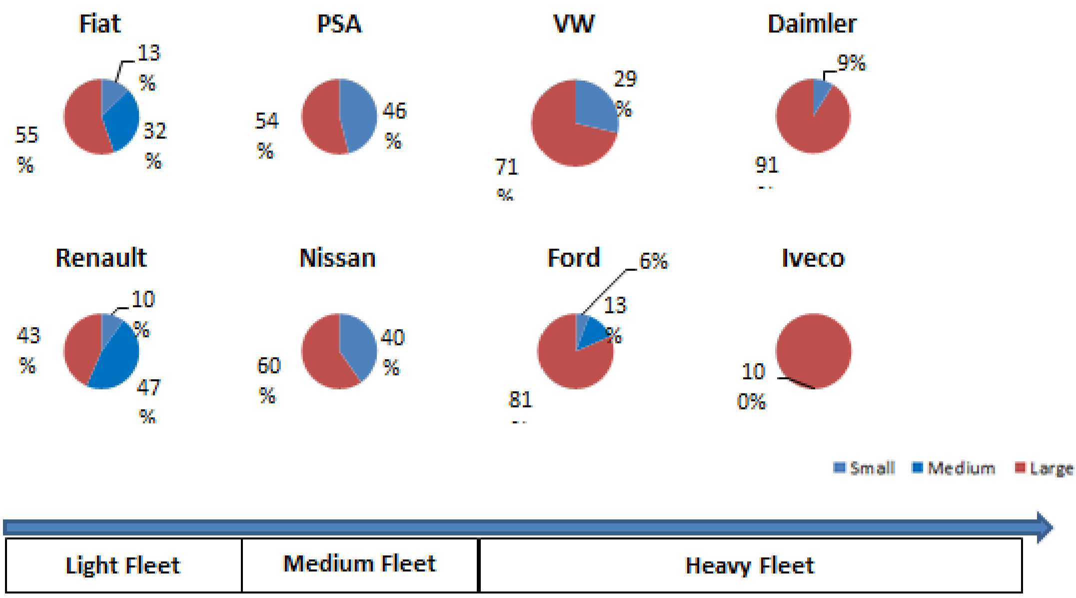



**Figure 2 – Definition of LCV manufacturers**

In addition, different manufacturers have been using platform sharing based on an agreement to declare their partnership in order to combine engineering, design and production experiences on different kind of vans, thereby, they can improve their manufacturing economies by minimizing engineering development costs and saving great number of separate components and using efficiently production facilities, meanwhile, attracting current and future customers with greater product variety. [7] Some vehicle platform sharing examples are shown below with cooperation of other manufacturers or different models of the same brand:

**VW Modular  Electric Drive Matrix (MEB) Platform**: Ford will deliver up advanced electric vehicles with a combined 8 commercial vehicles based on Volkswagen' Modular Electric drive Matrix (MEB) platform.

**PSA Efficient Modular Platform2 (EMP2):** Citroen (Berlingo III, Jumpy III), Peugeot (Partner/Rifter, Expert), Opel (Combo, Vivaro), Toyota (Proace)

**Platform x290**: Fiat (Ducato), Citroen (Relay), Peugeot (Boxer)

**Sevel Platform**: Fiat (Fiorino), Peugeot (Bipper), Citroen(Nemo) [8]

## 2.5 Powertrain Types of LCVs

There is no doubt that the vast majority of Europe's fleets of LCVs are constituted by vehicles with diesel engine powertrains for the reasons that their characteristics of high torque, huge loading capacity, better fuel economy so that customers base their decisions on diesel-powered vans thanks to its fuel efficiency and enduring performance. However, the most recent decade, between the period of 2010 and 2020, is an important period for LCV market due to more stringent regulations sanctioned by EU with the aid of reducing the pollutant emissions and noise level in Europe, OEMs have been undergoing a radical change in their fleets so that alternative powertrains as described in below are prepared for the penetration to market heavily;

**Hybrid Electric Vehicle (HEV)**: Hybrid vehicles have at least one electric machine which can be operated as a motor or a generator and a battery as energy storage (hybridization unit: ICE + E-generator+ power converter) in addition to conventional vehicles.  The main advantage (for parallel hybrids) is the high flexibility by using pure thermal mode, pure electric mode and hybrid mode but limitation is higher system complexity. There are three main types of hybrid vehicle:

Micro HEV is able to automatically shut down the engine and save fuel while the vehicle is at a standstill and then restarts it when the brake pedal is released, called start-stop function. Fuel economy improvement is around 3-5% depending on road conditions.

Mild HEV is similar to Micro HEV but additionally it offers regenerative braking and supply assist torque for internal combustion engine with the integrated advanced alternator and it is installed with stronger electric components and provides power for starting and accelerating at low speeds.

Full HEV has much larger components while it has the same e-motor, alternator and battery with a smaller engine. Even though it is a more complex control strategy than mild hybrid, Full HEV offers a higher fuel economy around 20-30%, consequently emits lower CO2 emissions because of its ability to drive smaller distances in purely electric mode.

**Plug-in Hybrid Electric Vehicle (PHEV)**: PHEVs are different with respect to full-hybrid with the characteristics of having a downsized engine, more advanced e-motor and alternator and larger capacity of the battery which can be charged externally. Performance of the PHEV, just like every electrified vehicle, depends on the battery that is able to meet the requirements such as supplying sufficient peak power for high performance and ensuring high level of safety combining with an IC engine which can be diesel or petrol. Until 50 km driving range, it is able to run without emitting exhaust gas thanks to rechargeable battery packs while hybrid mode is switched for longer distances. Nowadays, even most of PHEVs have been selling more in the passenger car market, there are increasing new registrations for Plug-in Hybrid LCVs in Europe.

**Range Extender Electric Vehicle (REEV)**: Internal combustion engine is only used to generate electricity and this arrangement can be called as series hybrid powertrain. The range depends on the power pack tank capability and the main hybridization goal is to increase the original battery electric vehicle range (on the sizing cycle) reducing volume and weight of its battery pack with very limited noxious emissions.

**Battery Electric Vehicle (BEV)**: BEVs have rechargeable batteries that store the electricity onboard and they are used to drive electric motor. They have important advantages such as zero noxious emissions, low noise emissions, zero Tank to Wheels (TtW) CO2 emissions, low operation costs with high efficiency. On the other side, in recent conditions, BEVs have some drawbacks that are: limited range of 100-200 km only for urban usage, long charging times and 2-4 times higher purchasing price with respect to equivalent conventional vehicles.

**Fuel Cell Electric Vehicle (FCEV)**: The device called Fuel Cell is able to directly convert chemical energy into electricity, through the electrochemical reaction between hydrogen and oxygen by producing water, electricity and heat without combustion. Fuel Cell uses fuel coming from an external source different from battery but they are fuelled with hydrogen and oxygen. In automotive applications, the Polymeric electrolyte (PEM) Fuel Cell which can be explained as hydrogen and oxygen combined to produce an electric current is cheaper with respect to other fuel cell types and having lower operating temperatures, faster response and safety as well. But there are some technical and economic barriers for hydrogen structure such as high capital cost of pipelines, high cost of compression and high cost of liquefaction because of these reasons FC technology is not so common on LCV sector and for the sake of simplicity in this report only previous technologies have been analyzed on LCVs fleet evolution beyond-2020.

Based on Ricardo's study, 68% of ICE light duty vehicles (<3.5t) with stop/start were running on the EU'S road while vehicles with alternative fuel made up lower than 2% in 2015. Approximately 16% of the European parc will be alternatively-powered vehicles that 9% are PHEV, followed by BEV with 5% and FCEV are only 2%, however, partially electrified vehicles, HEV, will maintain its majority with stop/start ICE (40%), MildHEV (40%) and HEV(4%) in 2025. Progressively, the alternative powertrain market will increase its market share by about 27% while MHEV remains constant in 2030. [9]

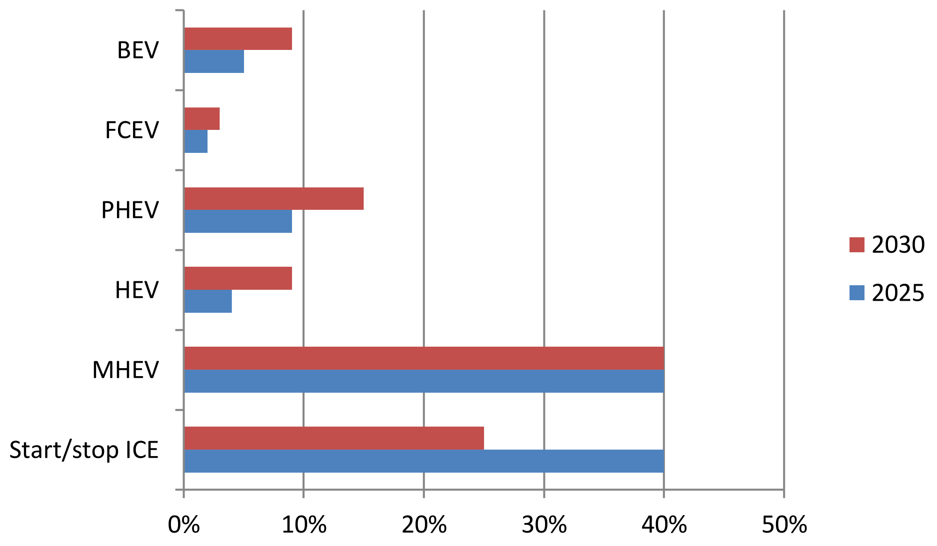



**Figure 3 - Vehicle Mix Estimation in the future European parc by Ricardo Consulting**

Another forecast published as roadmap by Advanced Propulsion Centre UK, for the products with low power request, like car-derived van, BEV and ICE+HEV (without specifying which type of HEV) technologies will be the upward trend after 2020 by focusing on emission zone compliance and cost reduction strategies with increasing the low-speed efficiency. On the other hand, for other segments of light duty vehicles, usage of hydrogen energy source with ICE+HEV technology is predicted beyond 2020 and BEVs will take an active role provided that higher range without charging. Fuel cell technology is not foreseen to be attractive until 2030. [10]

### 2.6 Market Analysis

In 2018, totally 17.5 million vehicles were sold in EU-28 and passenger cars had a market share of 86% with the highest volume while LCVs and trucks/buses (>3.5 t) split the difference with 12% and 2%, respectively. According to ACEA report, there were a total of 33.2 million LCVs on the EU's roads in 2018 and 91,2% of all vans are running on the roads with diesel engines while petrol-powered LCVs are in the minority on average in Europe. [11]

In the EU, France is always the far largest LCV market that forms the one fourth of new LCV registrations data supplied from ICCT since 2012, followed by the United Kingdom and Germany. Even if the population is taken into account for these countries which France (66.89 million in 2018) has less citizens than Germany (82.79 million in 2018) and equal to United Kingdom (66.27 million in 2018) more or less so the gap between the rate of LCV/population have been increasing remarkably. [12]

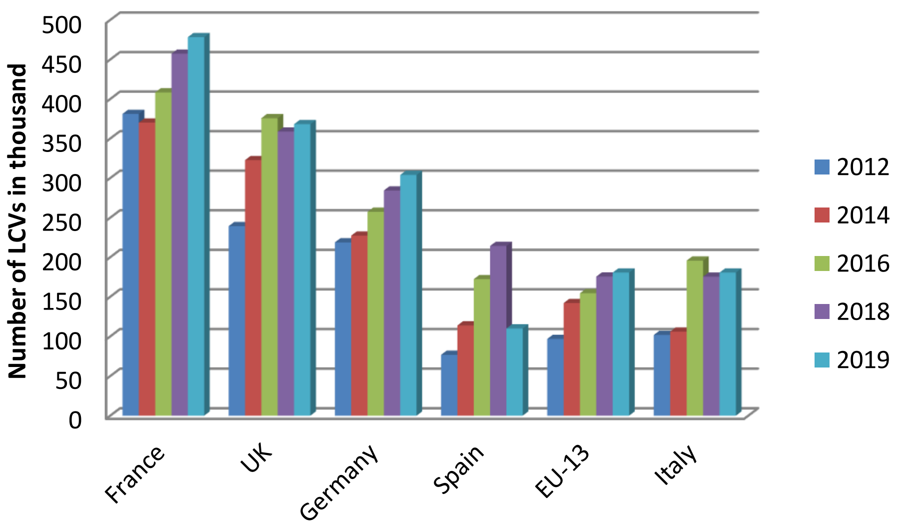



**Figure 4- Newly registered LCVs in Europe between 2012 and 2019**

Market share EU-28 shows that diesel share of new LCVs registrations in 2013 was 98% while their market share has slightly dropped to 96% in 2019 but still they remain the only major powertrain that is very popular for OEMs and LCVs with petrol engines get a 4% share of the cake. On the other hand, total sales registration of LCVs with alternative powertrains such as Plug-in Hybrids, battery electrics, fuel cell and hybrid technologies have been increasing significantly while conventional light commercial vehicle registrations with natural gas (including LPG) show a dramatic reduction in van market since 2010. As it can be seen from the figure, battery electric vehicle registrations break even CNG in total new registration numbers in 2014 and its production number accelerates between 2016 and 2020. Also it can be seen that there is an absence of production of LCVs with PHEV technology until 2018, after its introduction in market in 2019, PHEV develops its sale number four times for this year. [13]

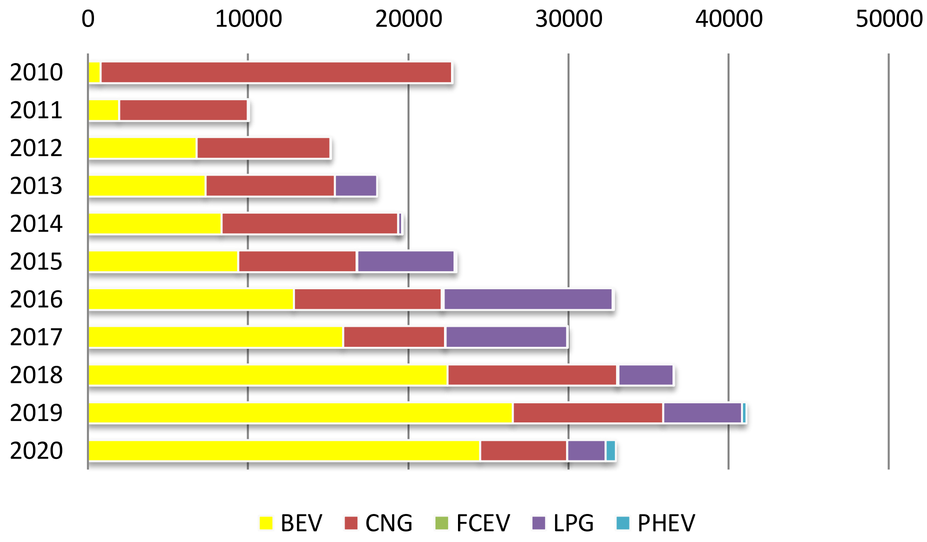



**Figure 5 - Alternative fuel new registrations from 2010 to 2020**

Even though electric vehicles demonstrate an increasing trend during the past decades, the LCVs with CNG and LNG that have mostly converted to natural gas-fuelled vehicles starting from 2013 still maintain their majority in the alternative fuel fleet in Europe. But as the new registrations of electrified powertrains continue its constancy, it is probable that the total number of natural gas-powered vehicles will become a minority by taking into account their diminishing utility for manufacturers. [13]

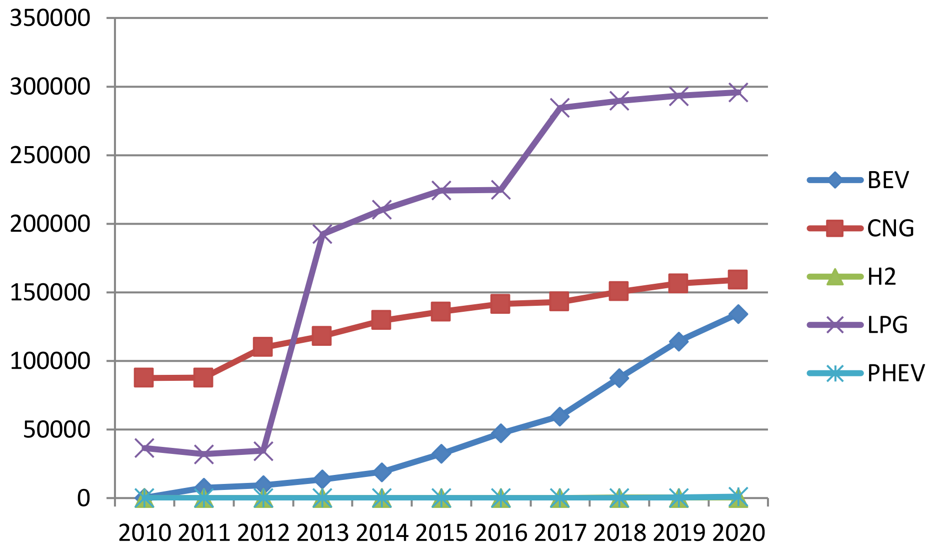



**Figure 6 – Total number of registered LCVs with alternative powertrains**

Moreover, it is interesting that the country which has the highest total registrations of battery electric vans is France within the top 5 country alternative fuel fleet with 55,124 units while Germany and the United Kingdom have a total number of 23,422 and 11,501, respectively. [13]

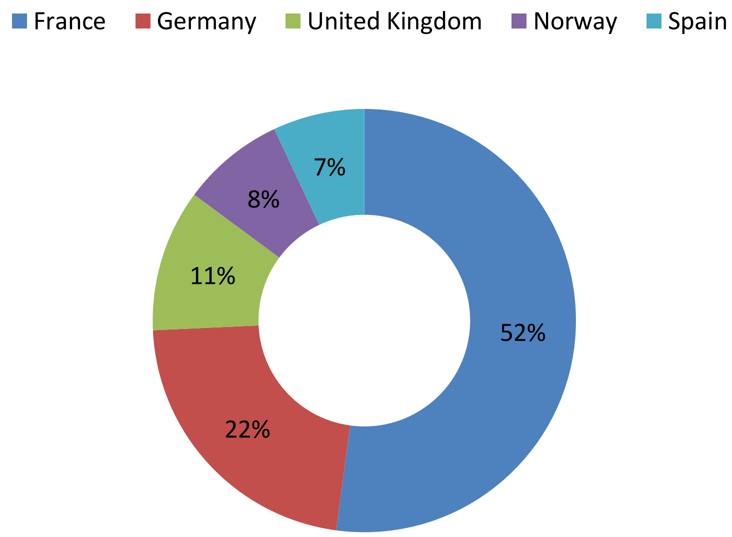



**Figure 7 - Top 5 Country AF BEV Registrations (2020)**

On the other side, PHEV has an upward trend in the UK and Italy has the highest LCV registrations for CNG fuel type by far while LPG is the biggest market in Poland. Overall, it is clear that France is leading the e-LCV market in all European countries even though it seems that Poland has the largest alternative fuel LCV fleet thanks to its higher vehicle registrations with LPG fuel. In conclusion, obviously BEV powertrain type has gained momentum since 2011 and it is getting the most popular powertrain type in Europe as it can be seen from the new registration number of BEV in 2019 has almost trebled the CNG which is the nearest rival. Additionally, PHEV new registrations have been increasing within the past 3 years but there is almost no FCEV market share in European LCV fleets. [13]

According to JATO Dynamics 4 key LCV segment registrations in first quarters of 2017 and 2018, car-derived, small and compact segment occupy the more or less 32-31% of the van market in both years, similarly, midsize segment of LCVs remains unchanged with the market share of about 28-27% after one year while large segment and pickup segment increase their new registrations, sharing 29% and 11-10% of LCV market, respectively. [14]

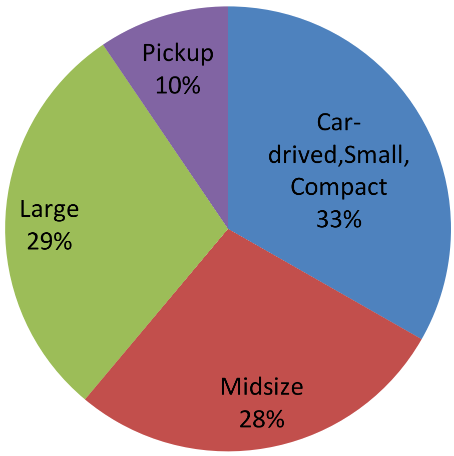



**Figure 8 - Market shares of LCV segments in 2018**

In terms of manufacturer brands, Renault was the top seller among OEMs until 2017 but there is a turning point in the year of 2018 when Ford registered the highest number of new LCV with 341,032 units but Renault still led the sales of BEV models with Nissan. [12]

Ford Transit is the most popular van model in all segments in the EU in 2018 with the sales number over 284,000 and even there is no clear win between compact segments Citroen Berlingo has the 4.5% of the LCV market sales while VW Transporter is the most preferred midsize segment [12].

Top 6 best-selling e-LCVs in Europe are shown in the figure between the period of 2017 and 2019. The French automaker has become the best-selling full electric van with its compact van Kangoo Z.E. over 9000 new registrations by taking into account Europe, EFTA countries and the UK while its partner Nissan has doubled its total new registration number by developing a new battery pack of  Nissan e-NV200 in 2019. On the other hand, DHL's delivering van remains always within the top three selling vans with Street Scooter Work despite it shows a sudden decrease in 2019. Another French van maker, Group PSA, has been on the decline in the last three years; however, they have developed its new generation compact vans as well as LCVs of midsize and large segments in order to keep up with increasing trends starting from 2021 [13].

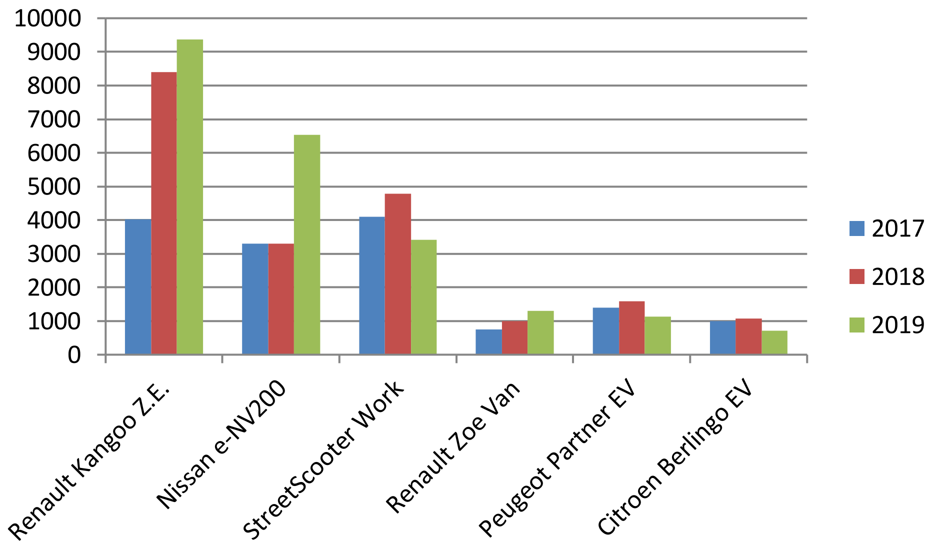



**Figure 9 - Top 6 Best-selling e-LCVs in Europe between 2017 and 2019**

As it can be seen from the graph, CO2 emission levels in Europe have decreased dramatically from 180 g/km (NEDC based) to 160 g/km (NEDC based) in 2019 within last decade and 2020 average CO2 emission target is 147 g/km for all European fleet, still this target will be reduced by 15% in 2025 and by 31% in 2030 based on 2021 wide-fleet target (WLTP based) [12].

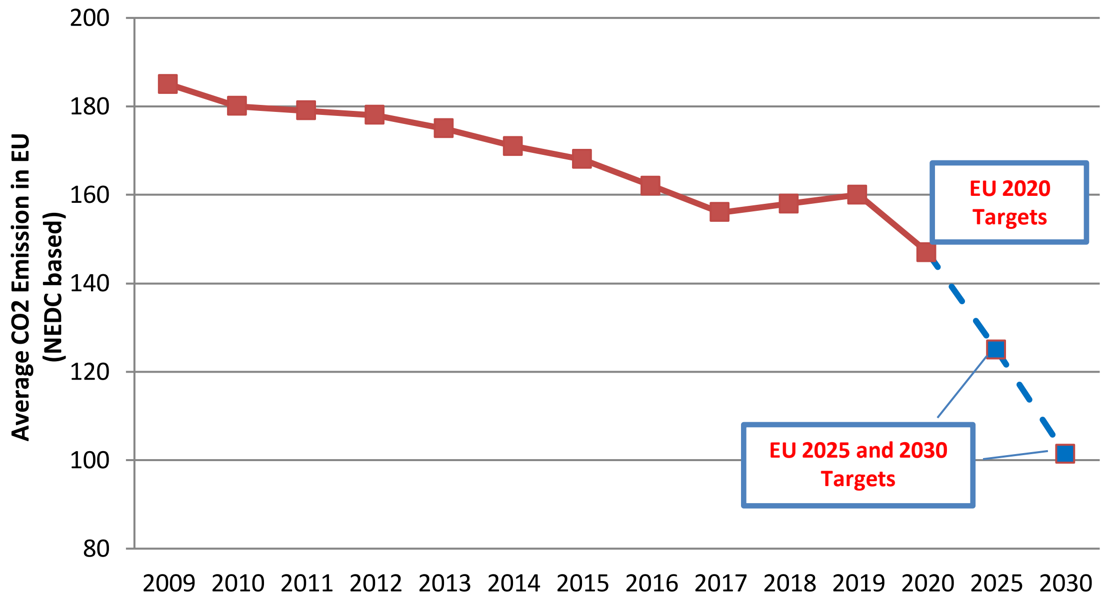



**Figure 10 - EU LCV Emission History between 2009 and 2025**

In 2018 almost all LCV manufacturers met their specific targets except Iveco, Mercedes-Benz and Mitsubishi even EU regulation sets 175 g/km fleet target until 2017. Some manufacturers like Renault, Citroen, Peugeot and Dacia have already complied with the EU emission 2020 target [12].

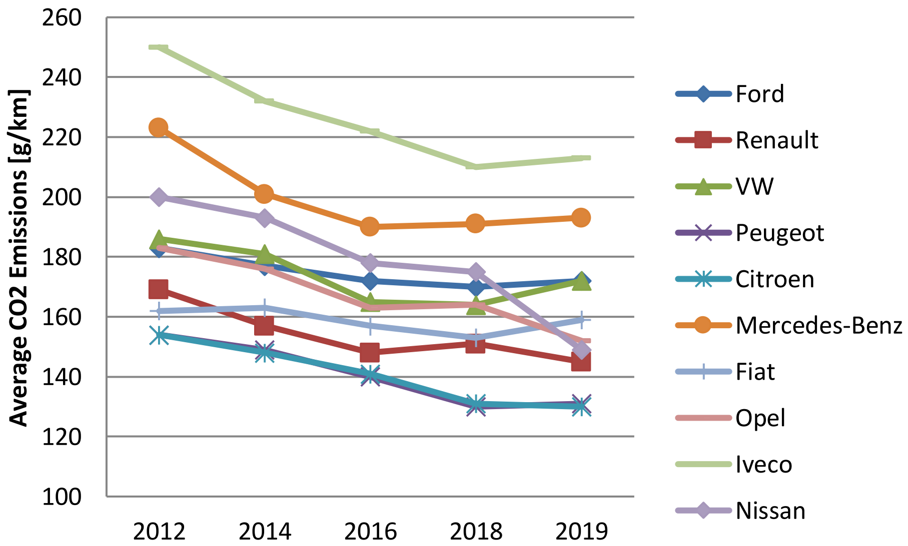



**Figure 11 - Average CO2 Emissions by brand**

Until 2021, OEMs have to meet an average CO2 target of 147 g/km for emission levels of new registered vehicles based on the average vehicle mass in their fleets. In this term, the member state countries of Portugal, France, Spain and Italy are the most green with their lower average emission levels while Germany has a CO2 emission spectrum higher than 175 g/km. On the other hand, French Automotive companies are the most successful in lower emission reduction with four brands.

Another important aspect for the new emission regulations to emphasize is that average vehicle mass in running order of LCVs has increased from slightly over 1600 kg to higher than 1870 kg from 2011 to 2019 in the EU.

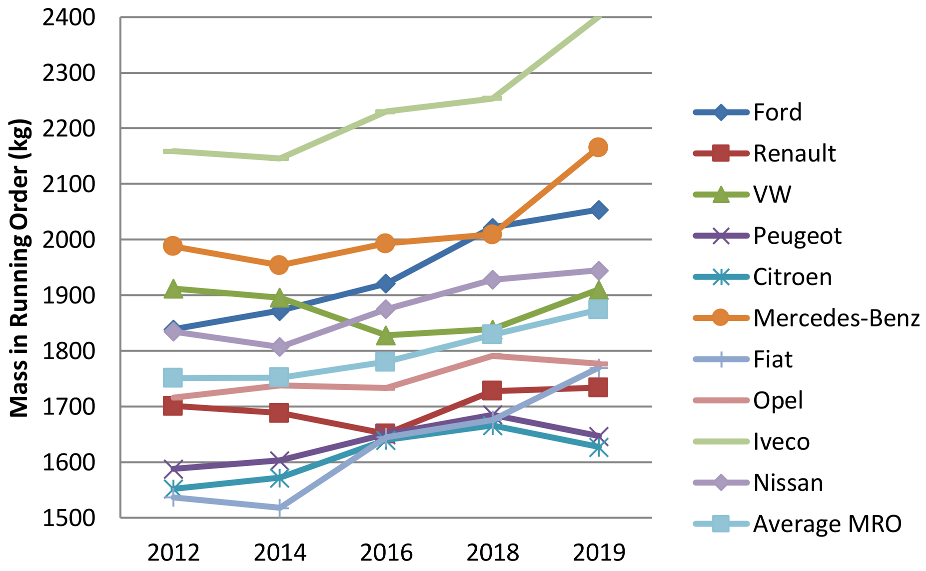



**Figure 12 - Average mass of LCVs by brand**

Charging infrastructure is playing a key role in order to offer better performance of electric vehicles and meet the requests of drivers to have easy access to charging stations. Charging infrastructure can be public or publicly accessible locations or lands owned privately. The charging points have a standard power supply by diversifying as slow (<= 7.4 kW), accelerated (7.5 kW<P<=22 kW), fast (22 kW<P<=50 kW) and ultra-fast types (>50 kW). As it can be seen from the graph, both the fast and normal charging infrastructure investments have been gradually increasing since 2014 and today there are more than 190,000 normal charging points in the EU [13].

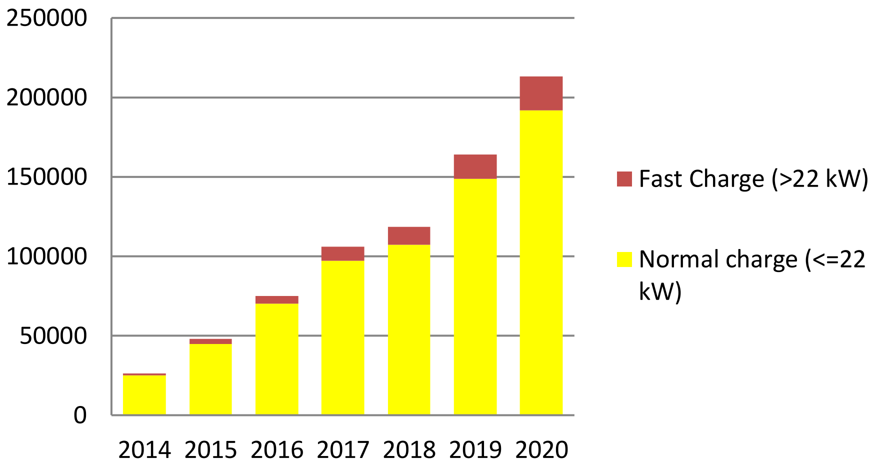



**Figure 13 - Total Number of Fast and Normal Charging Points in EU**

The table represents the data for top 5 countries with the highest public charging points in 2020. With regards to the number of charging infrastructure, Netherlands has the largest network of over 60,000 charging points, followed by France and Germany with registered 44728 and 42740 public charging respectively in the EU in 2020 [13].

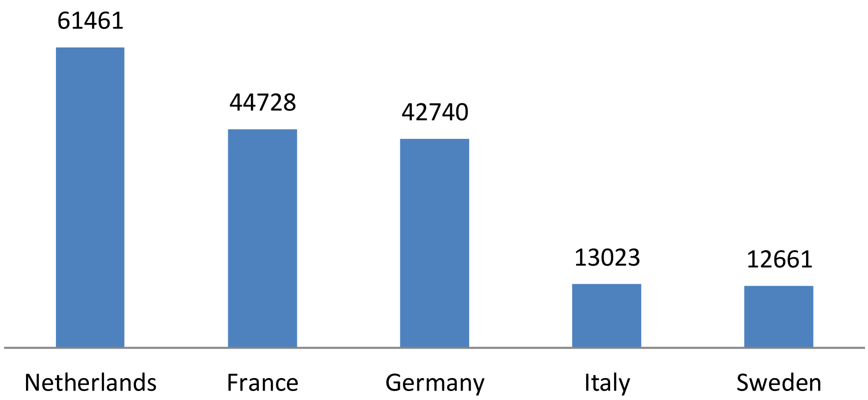



**Figure 14 - Top 5 countries Number of public recharging points in EU (2020)**

The figure depicts the history of electricity cost for household consumers with taxes between 2016 and 2020 in EU-27. The electricity prices remained almost unchanged from 2016 until the second half of 2018 and then showed a remarkable increase in the mid-2018. In the first half of 2020, electricity cost has decreased but still remained higher with respect to the average electricity price of previous years [15].

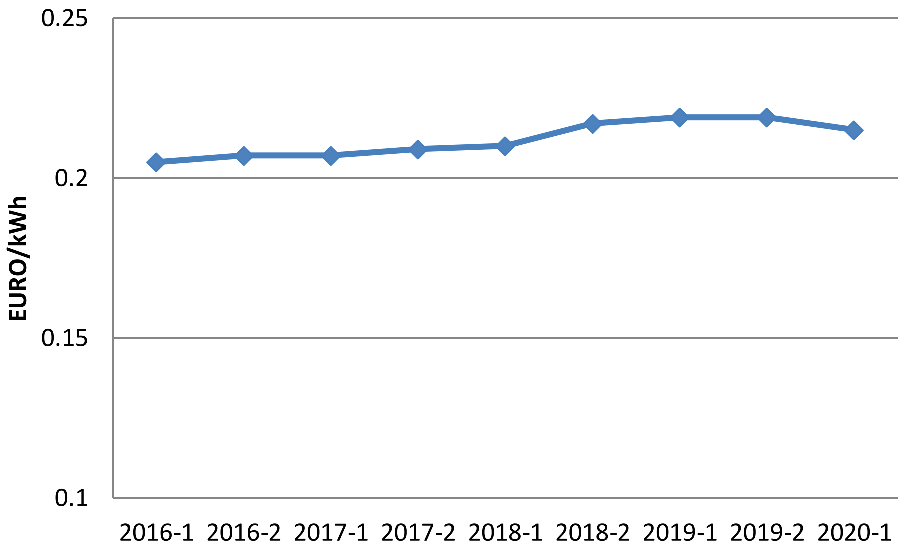



**Figure 15 - Electricity prices for household consumers between 2016 and 2020**

Fuel prices have been fluctuating both for diesel and petrol types with a similar trend that there was a sudden drop in fuel prices between the second half of 2014 and in the beginning of 2015 then a peak occurred in the half of 2015 and again showed a significant decrease in 2016. Diesel and petrol prices have an increasing trend until 2018 and then they show a sharp decrease at the end of 2020. [16]

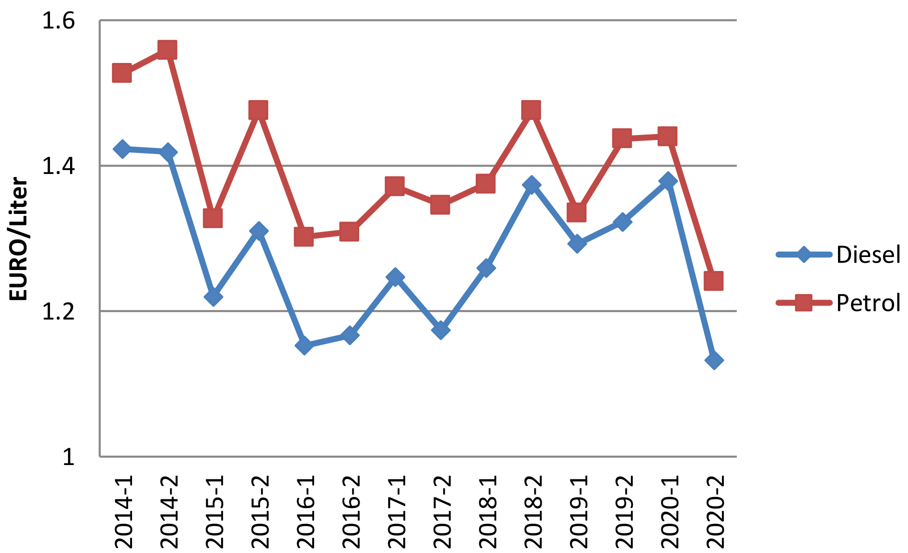



**Figure 16 - Fuel prices development from 2014 to 2020**

## 2.7 Main drivers in LCV market post-2021 in EU

In global scale, even the European automotive market is successful at leading the patent industry over the world, China and Japan have a strong technological deployment with regard to low/zero electric vehicles. If the new and more severe greenhouse gas standards such as The Zero Emission Vehicle (ZEV) program that requires the car manufacturers to sell battery electric, plug-in hybrid, and fuel cell vehicles in U.S. (nine states adopted both ZEV and LEV programs) or the New Energy Vehicle (NEV) requirements launched by China's government to support the alternative electrified vehicle technologies from 2021 to 2035 are taken into account, European industry is under risk to lose its global technological leadership across these new ambitious policies unless reflecting its know-how over electrification technologies [17]. However, specifically in the EU, there are major factors affecting the light commercial vehicles that have explained below:

- **Customer's concerns about electric vehicles**: The main concern depends on the mental barrier that the new technology looks unreliable from the LCV buyer's point of view. Secondly, electrification infrastructure of the LCVs has not potential as high as passenger cars because of their purpose of usage in different business areas and mileage profiles it is required to have a special attention to design a van. This is the reason why consumers are recessive about the driving range of the battery that is limited to recharge it after a certain distance as well as inadequate charging infrastructure in city centers by waiting for long charging times. Another important aspects about purchasing and productivity are that consumers are not willing to pay more initially for a hybrid or electrified LCV as their price seems to be gigantic with respect to conventional vehicles despite the fuel and energy savings potential of these powertrains and restriction of other characteristics like payload is not acceptable as batteries occupy a wide area on the purpose of LCV business [18].
- **EU Directives and local air quality regulations**: Firstly, a new method for the type-approval CO2 emissions of light-duty vehicles has been introduced by EU, namely Worldwide Harmonized Light Vehicle Test Procedure, replacing with New European Driving cycle (NEDC) in order to reflect better the real-world fuel consumptions and emission levels. Also, the EU Commission's current regulations set an EU fleet wide target of 147 g/km for LCV manufacturers for 2020 in Europe. According to EEA data, 2017 EU fleet wide target of 175 g/km had already been achieved four years before, in 2013, so OEMs were able to meet the EU requirements with conventional

vehicles that fuelled with diesel in majority in their fleet. However, based on the provisional data, newly registered vans in 2019 had 158.4 g/km which is much higher than the 2020 target in EU-28. Moreover, the EU agreed stricter rules for the new vans registered in 2025 and in 2030 to be lower 15% and 31%, respectively, based on the 2020 targets. On the other hand, especially after the diesel gate scandal, some European cities have decided to close their roads for the vehicles below a certain Euro emission level by creating Low-Emission Zones (LEZ) in order to decrease the NOX emissions. Every country has its own LEZ program with different requirements, for example, petrol cars with Euro1 and diesel cars with Euro3 and Euro4 are not allowed to enter the LEZ zones in Germany while Ultra Low Emission Zone (ULEZ) in London will not allow the Euro4 for petrol vans and Euro6 for diesel vans. Overall, policy requirements both for vans manufacturers and customers stimulate the development of the electrified vehicles market to reduce the air and noise pollution from EU road transport. [19]

- **Future technology developments of manufacturers**: Basic process of a vehicle development cycle is controlled with the strategic product planning timeline that consists of concept development, series development, series preparation and start of series production. If it is taken into account that the development and production processes of LCVs take much more time than passenger cars, manufacturers do not have enough lead-time to develop and introduce a new LCV on 2025 in the market starting from today so they have can have roadmap to adapt their fleets according to 2030 CO2 target limits. The main drawback for the near future is that new e-LCVs are not able satisfy the mission of a commercial vehicle in terms of, typically first complaint of buyers, load constraints and battery range because, from a volumetric point of view, customers have to pay €25 per kilogram payload for conventional diesel powered van while almost double paid for electrified one in the same segment. Additionally, battery packs depending on capacity increase the vehicle curb weight so according to light commercial vehicle definition extra weight could cause to exceed the threshold defined for each class, especially for large segments. In conclusion, during the electrified vehicle development process OEMs have to take into account consumers' attitudes and concerns as well as their business profitability for a better market positioning. [18]
- **Incentives and ZLEV credits**: European countries have been supporting the electric vehicles production and sales with purchase subsidies and tax reductions including registration and road tax in order to increase financial attractiveness of low/zero emission vehicles but the type and amount of these incentives vary in different member states so that these benefits have

a significant effect on total cost of ownership for private customers or fleet operators. On the other hand, EU LCV regulations established super-credits which will be replaced with ZLEV 2025 onwards based on the production of zero/low emission vehicles emitting emissions less than 50 g/km for the purpose of encouraging the manufacturers with given additional incentives that CO2 emission target for OEMs could be increased with a limited proportion of van.

# 3 PEST ANALYSIS OF LCV MARKET IN EUROPE BEYOND 2020

Due to LCVs large size of mass-market, there are several factors that influence the economic growth, market dynamics and its future scope and limitations in terms of creating alternative strategic plans. In this part, four main factors that are political, economic, social and technological are discussed regarding LCVs changing the environment through CO2 challenge 2020 onwards.

## 3.1 Political factors:

### 3.1.1 EU Regulations

According to Regulation (EU) of No 510/2011 of the European Parliament and of the Council, published on 11 May 2011, the regulation requires an average CO2 emissions of new LCVs to meet 175 g/km at least but same regulation sets for the new registered LCVs in EU a target of 147 g/km from 2020 onwards. [20]

#### 3.1.1.1 Specific CO2 Emissions Target Calculation

In order to calculate the specific emission targets, the mass of the vehicle (M), reference mass (M0) and slope (a) have taken into account to calculate indicative specific emissions of CO2 for each LCV with following formulae:

Between 2014 and 2017:

$$\text{Specific emission target} = 175 + a * (M - M_0)\ [\text{g CO2/km}] \qquad \textbf{(3.1)}$$

where: a=0,093 and M0=1706,0

from 2018:

$$\text{Specific emission target} = 175 + a * (M - M_0)\ [\text{g CO2/km}] \qquad \textbf{(3.2)}$$

where: a=0,093 and M0=1766,4

from 2020:

$$\text{Specific emission target} = 147 + a * (M - M_0)\ [\text{g CO2/km}] \qquad \textbf{(3.3)}$$

where: a=0,096 and M0=1766,4

#### 3.1.1.2 The correlation methodology for CO2 emissions measurement on the basis of both NEDC and WLTP

According to Regulation (EU) No 2017/1151, a new test procedure, World Harmonized Light Vehicles Test Procedure (WLTP), in order to measure fuel consumption and CO2 tail-pipe emissions in a more realistic way has been set starting from 1 September 2017 [21]. WLTP has developed depending on the combination of in-use data collected in different areas in the EU, USA, Japan, India and Korea taking into account more severe weather conditions and a weighting factor matrix. It consists mainly of 4 phases; low, middle, high and extra high speed so, as a result, WLTP represents more dynamic driving conditions as shown in comparison between NEDC and WLTP in the table below.

| Characteristics / Driving Cycle | NEDC | WLTP |
|---|---|---|
| **Distance (km)** | 11 | 23,3 |
| **Duration (s)** | 1180 | 1800 |
| **Max Velocity (km/h)** | 120 | 131,3 |
| **Mean Velocity (km/h)** | 33,6 | 46,5 |
| **Acceleration (s)** | 247 | 762 |
| **Deceleration (s)** | 539 | 730 |
| **Constant Driving (s)** | 493 | 98 |
| **Stop (s)** | 280 | 226 |

**Table 1 – WLTP vs. NEDC comparison**

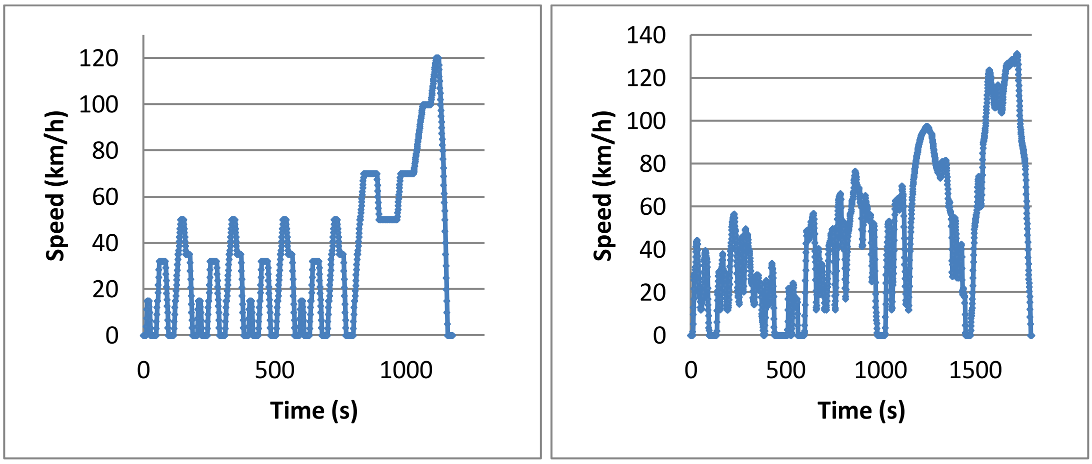



**Figure 17 – NEDC vs. WLTP Driving Cycles**

Because of that a correlation methodology has to be used by taking into account WLTP and NEDC measurements but the target will be defined for NEDC for 2020 so that CO2 emission targets can be checked on the basis of NEDC values until 2020. Then, WLTP based specific CO2 emission targets will be determined from the calendar year 2021 as follows:

WLTP specific emission reference target $= WLTP_{CO2} * \left(\frac{\mathbf{NEDC2020target}}{\mathbf{NEDCCO2}}\right)$ **(3.4)**

Where:

$WLTP_{CO2}$ , is the average specific emissions of CO2 in 2020 without adding super-credits or eco-innovations

$NEDC_{CO2}$, average specific emissions of CO2 in 2020 without adding super-credits or eco-innovations

$NEDC_{2020target}$ , specific emission target of 2020 for each OEM

#### 3.1.1.3 Specific Emission Reference Target for a manufacturer from 2021 to 2024

Specific emission target $= WLTP_{reference\ target} + a\ [(M_{ø} - M_0) - (M_{ø2020} - M_{0,2020})]$ **(3.5)**

Where:

$WLTP_{reference\ target}$ is the 2021 specific emission reference target calculated as above

a is 0,096

$M_{ø}$ is the average mass (M) of the new registered light commercial vehicles in the target year in kilograms (kg)

$M_0$ is 1766,4 kg in 2020, to be updated for 2021, 2022, 2023 and 2024 for light commercial vehicles

$M_{ø2020}$ is the average mass (M) of the new registered light commercial vehicles in 2020 in kilograms (kg)

$M_{0,2020}$ is the $M_0$ value applicable in the reference year 2020.

From the beginning of 2025, in order to calculate the EU fleet-wide targets and the specific emissions targets for a manufacturer following formulae will be used [21]:

EU fleet-wide $target_{2021}$ will be defined as the manufacturer specific reference values of the average number of new light commercial vehicles sold for 2021.

2021 specific reference value = $WLTP_{CO2,measured}$ * ($\frac{\mathbf{NEDC2020fleet\ target}}{\mathbf{NEDCCO2}}$)+ a*($M_{ø2021}$ – $M_{0,2021}$) **(3.6)**

where:

$WLTP_{CO2,measured}$ is the average, for each manufacturer, of the measured CO2 emissions combined of each new light commercial vehicle registered in 2020

$NEDC_{2020,Fleet\ Target}$ is 147 g/km

$NEDC_{CO2}$ is average specific emissions of CO2 in 2020 without adding super-credits or eco-innovations

$M_{ø2021}$ is the average of the mass in running order of the new light commercial vehicles of the manufacturer registered in 2021 in kilograms (kg)

$M_{0,2021}$ is the average mass in running order in kilograms (kg) of all new light commercial vehicles registered in 2021 by manufacturers whom specific emission target applied

#### 3.1.1.4 The EU CO2 targets for 2025 and 2030

The EU Commission has set new CO2 emission reduction targets for the years of 2025 and 2030, published as regulation 2019/631 [22]. According to this regulation, the fleet-wide and specific emissions reference targets are calculated based on EU fleet-wide target of 2021 as the following:

- EU fleet-wide target for 2025 and 2030

EU fleet-wide target2025 = EU fleet-wide target2021 · (1 – reduction factor2025) **(3.7)**

EU fleet-wide target2030 = EU fleet-wide target2021 · (1 – reduction factor2030) **(3.8)**

where:

EU fleet-wide target2021 is defined as above;

reduction factor2025 is the 0,15

reduction factor2025 is the 0,31

- Specific emissions reference targets from 2025 and 2030 onwards

The specific emissions reference target 2025= EU fleet-wide target2025 + α · (TM – TM0) **(3.9)**

The specific emissions reference target 2030= EU fleet-wide target2030 + α · (TM – TM0) **(3.10)**

where:

EU fleet-wide target2025, 2030 is as determined above:

TM is the average test mass of manufacturer's new light commercial vehicles registered in the relevant year

TM0 is the average test mass of new LCVs in two calendar years (beginning with 2022 and 2023)

α is a2025 where the average test mass of a manufacturer's new light commercial vehicles is equal to or lower than TM0 determined as:

a2025 or a2030 = a2021 * $\frac{\textbf{EU fleet-wide target 2025,2030}}{\textbf{average emissions 2021}}$ **(3.11)**

a2021 where the average test mass of a manufacturer's new light commercial vehicles is higher than TM0 determined as:

a2025 or a2030 =a2021

a2021 is the slope of the best fitting straight line by using linear least squares fitting method to the test mass and the specific emissions of CO2 of each LCV registered in 2021.

- The specific emissions target 2025 and 2030

Specific emissions target2025, 2030=( The specific emissions reference target 2025,2030 – (øtargets – EU fleet-wide target 2025,2030))*ZLEV factor **(3.12)**

Where:

Øtargets: number weighted average of LCVs of each individual manufacturer newly registered, of all the specific emissions reference targets

ZLEV factor is defined in the Incentives section.

#### 3.1.1.5 EU LCV manufacturers CO2 emissions in 2019 and estimated 2020 targets

According to ICCT EU vehicle market statistics, $CO_2$ emission averages and masses of vans manufacturers (without pooling) are shown on table with estimated 2020 targets based on 2019 values by taking into account equation (3.3). It is clear that most van manufacturers face billions in fines for exceeding their target levels [12]. As it can be seen from the table, Peugeot, Renault and Ford are able to achieve their 2020 target with business as usual but other manufacturers have to heavily invest on improvements on ICE vehicles or changing their strategies with electrification in order to comply with $CO_2$ emission regulations.

| Manufacturer | NEDC $CO_2$ Emission (g/km) | Average Mass (kg) | 2020 Target (estimated) |
| --- | --- | --- | --- |
| Ford | 172 | 2054 | 175 |
| Renault | 145 | 1734 | 144 |
| VW | 172 | 1910 | 161 |
| Peugeot | 131 | 1647 | 136 |
| Mercedes-Benz | 193 | 2166 | 185 |
| Fiat | 159 | 1770 | 147 |
| Iveco | 213 | 2401 | 208 |

**Table 2 - Average Emissions and estimated 2020 targets of LCVs**

#### 3.1.1.6 Adjustment of M0 and TM0 values

The new M0 value that has to be calculated as an average mass in running order of new LCVs registered in 2019, 2020 and 2021 will be applied in 2024. The indicative TM0 for 2025 will be determined based on the average test mass of newly registered LCVs in 2021.

#### 3.1.1.7 Excess Emissions Premium

The Commission has imposed an excess emissions premium on OEMs or pool managers exceeding the specific emission target. The excess emissions were calculated according to following formulae between 2014 and 2018:

- For excess emissions of more than 3 g/km:

Excess emissions premium= (Excess emissions – 3 g/km) * EUR 95 + EUR 45) * number of new light commercial vehicles

- For excess emissions of more than 2 g/km but no more than 3 g/km:

Excess emissions premium= (Excess emissions – 2 g/km) * EUR 25 + EUR 20) * number of new light commercial vehicles

- For excess emissions of more than 1 g/km but no more than 2 g/km:

Excess emissions premium= (Excess emissions – 1 g/km) * EUR 15 + EUR 5) * number of new light commercial vehicles

- For excess emissions of no more than 1 g/km:

Excess emissions premium= (Excess emissions * EUR 5) * number of new light commercial vehicles

But since 2019 the full excess emission premium has been fixed to 95 € per gram:

Excess emissions premium= (Excess emissions * EUR 95) * number of new light commercial vehicles

By taking into account the passenger car market, VW group is likely to pay over €9.19 billion fine if no change is assumed from 2018 to 2021 while the same penalty is about €5.4 billion for French automaker PSA [23] .

#### 3.1.1.8 Eco-innovation

In this regulation (No 510/2011), manufacturers are allowed to use innovative technologies ("innovative technology packages") in order to reduce emissions and meet their specific CO2 emission targets up to 7 g/km in a given year for their fleet. This value is valid until 2025. For example, two under recognized but having high potential to reduce emission from ICE vehicles eco-innovations are; engine encapsulation that isolate the engine from external to save fuel during cold start and coasting that help to lower emissions by 5.4 g/km [24] .

#### 3.1.1.9 Incentives

According to the Regulation (No 510/2011), there were additional incentives for the manufacturers having each new LCV with emitting less than 50 g/km CO2 emissions, defined as Low Emission Vehicles, from 2014 to 2017 with a condition that cannot exceed 25,000 LCVs per manufacturer. These vans were counted as 3,5 LCVs in 2014; 2,5 LCVs in 2015; 2,5 LCVs in 2016, 1,5 LCVs in 2017; and 1 LCV in 2018. However, there are no super-credits for the 2020 regulation but zero-and low-emission vehicles (ZLEV) has been defined for LCVs with CO2 emissions from 0 to 50 g/km depending on the sales of the ZLEV vehicles that is valid 2025 onwards. If the sum of the ZLEV factor, (1+y-x), larger than 1,05 or lower than 1, ZLEV factor is set to 1,05 and 1

Where:

X is 15% for 2025 and 30% for 2030,

Y is the share of ZLEVs in the LCVs fleet where each of them calculated as ZLEVspecific divided by total number of LCVs newly registered in relevant year

$$\text{ZLEVspecific} = 1 - \frac{\textit{specific emissions of } CO2}{50} \qquad \textbf{(3.13)}$$

#### 3.1.1.10 Pooling and Derogations

In order to meet the specific emission targets, manufacturers of new light commercial vehicles are allowed to form a pool together. In recent news, Honda and FCA joined together to form a pool with Tesla which is selling a number of super credits to be earned from the sales of low emission vehicles in order to meet their specific emission targets for the passenger car market in the EU.

It is possible to apply for derogation from the specific emissions target for the van manufacturers registering less than 22,000 new LCVs in the EU per calendar year.

#### 3.1.1.11 In-Service Certification

Vans manufacturers have to ensure the correspondence of the CO2 emission and fuel consumption values to certificate of conformity of LCVs and the same values of vans in-service measured based on WLTP. Also, type-approval authorities are responsible for verifying the appropriate type-approval of selected vehicles and to detect any modification with the aim of increasing vehicle performance during type-approval.

With the purpose of reducing the gap between values for real-world emissions and laboratory tests, the Commission will collect the data on the real-world CO2 emissions and fuel consumptions from the on-board portable devices using the new LCVs registered in 2021. Then, they will observe the difference between the real-world and laboratory measurements between the period of 2021 and 2026.

Concerning to current regulations, 2025 and 2030 CO2 emission targets are defined based on the percentage reduction of average 2021 WLTP targets that depends on the ratio between 2020 NEDC and WLTP emission values so that there are serious concerns about manufacturers may increase 2020 WLTP emission value with lower ratio respect to 2020 NEDC value by transition from NEDC to WLTP that make less efficient and lower 2025 and 2030 target values. [24]

### 3.1.2 Low Emission Zones (LEZs) in Europe

Primary pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), sulfur oxides (SOx) and particulate matter emitted during vehicle driving through their life cycle or during the production of the energy types (diesel, petrol, electricity or natural gas) cause air pollution in local areas by venting to the atmosphere which create poor air quality. In the long term, these pollutants have chemical reactions with each other resulting in secondary pollution and they altogether affect human health as a serious threat from respiratory systems to chronic illnesses. For this reason, the European Union has introduced health based standards to reduce the air pollution level so with the purpose of aiding this target, major parts of the EU member states have established a series of urban access regulations regarding different areas of cities prohibited from entering for vehicles with high levels of emissions. Most important type of access restriction scheme called Low Emission Zones (LEZs) classify the vehicles based on Euro standards or gross vehicle weight in order to determine if those vehicles are allowed to enter the area or needed to apply the amount of charge to be paid in case of vehicles are not eligible to access [25]. In this concept, rules in terms of accessing limited zones in some European cities are explained below according to LEZs standards.

- **Milan**

Over the past decade, Low Traffic Zone regulation has been using in Milan. There are two types of area, "Area-B" and "Area C" that cover the territory of Milan are forbidden to access for the vehicles emitting dangerous pollutants depending on Euro level.

The first one is "Area-B" that includes the large part of Milan territory works between Monday and Friday from 7.30am to 7.30pm for the traffic limitation of the following large vans. Diesel-powered vans with Euro 5 and petrol one with Euro 1 are able to enter the zone until 1 October 2022 while diesel LCVs with Euro 6 are allowed to access the area B by 2028. The penalty fee is €80 [26].

| Year | 2020-2022 | 2022-2025 | 2025-2028 |
|---|---|---|---|
| **Petrol** | Euro 1 | Euro 3 | Euro 5 |
| **Diesel** | Euro 5 | Euro 6 | |

**Table 3 – Area-B Urban Access Regulation in Milan**

Another urban access restriction policy, Area-C represents the historic area of the city, is active from Monday to Friday between 7.30am to 7.30pm. Vans with petrol engines (Euro 2) and diesel one (Euro 5) can enter the area until 1$^{st}$ of October 2023. Hence, petrol vans with Euro 3 and diesel vans with Euro 6 are free to circulate there by 2025. Then, diesel LCVs will be separated depending on Euro 6 level and registration date to check its eligibility to access Area-C by 2030 however all diesel vans will be banned 2030 onwards providing that Euro 7 diesel vehicles will be discussed later by the regional government. [26]

| Year | 2019-2023 | 2023-2025 | 2025 | 2028 | 2030 |
|---|---|---|---|---|---|
| **Petrol** | Euro 2 | Euro 3 | Euro 4 | Euro 5 | Euro 6 |
| **Diesel** | Euro 5 | Euro 6 | Euro 6 A / BC | | Banned |

**Table 4 – Area-C LEZ regulations in Milan**

- **Paris**

French Ministry of the Environment created the French Crit'air air quality certificate program that summarizes the environmental roadmap of Paris with a series of stickers covering all vehicle types according to European emission standards. The fine is €68 in case of disregarding the rule. So considering sticker 3 from 4th of July 2019 to 2021, Euro 2 for petrol vans and Euro 4 for diesel vans are able to access restricted zones from Monday to Friday between 8am and 8pm. When passing to another phase of Sticker2, urban areas will receive only diesel vans at least Euro 5 and petrol one at least Euro 4 between 2022 and 2024. However, after 2024 no more diesel vans will be allowed to circulate then both diesel and petrol LCVs will be banned 2030 onwards. [26]

| Year | 2019-2022 | 2022-2024 | 2024-2030 | 2030 onwards |
|---|---|---|---|---|
| **Petrol** | Euro 2 | Euro 4 | Euro 5 | ICE Ban |
| **Diesel** | Euro 4 | Euro 5 | Diesel ban | ICE Ban |

**Table 5 – LEZ regulations in Paris**

- **Brussels**

"Lage emissiezone" is implemented in the capital of Europe regarding entering a low emission zone for the allowed vehicles. The penalty fee is €350 for the vehicles registered in Belgium and €150 for vehicles registered abroad. Until 1st January 2022, diesel vans at least Euro 4 are allowed to enter the restricted areas while diesel engines with Euro 5 and Euro 6 can access the zones after 2022 and after 2025, respectively. Afterwards, the local government in Brussels decided to ban diesel-powered vehicles from 2030 onwards while gasoline and LPG vehicles will not be able to be registered in 2035 [26].

| Year | 2019-2020 | 2020-2022 | 2022-2025 | 2025 onwards |
|---|---|---|---|---|
| **Petrol** | | Euro 2 | | Euro 3 |
| **Diesel** | Euro 3 | Euro 4 | Euro 5 | Euro 6 |

**Table 6 – LEZ regulations in Brussels**

- **Amsterdam**

There are similar rules in the Dutch city centers, called Milieuzones in national language, to improve the environmental road transport quality in their cities. From 1st of November 2020, diesel vans at least Euro 4 are allowed to access low emission zones until 2025 because, eventually, Amsterdam will be preparing to exclude all petrol and diesel vehicles from city center allowing only electrified vehicles from 2030 onwards [26].

- **London**

Low Emission Zones requirements have been implemented in almost all parts of London since 2008 and additionally, the Ultra-Low Emission Zone is introduced in 2019 in order to reduce the emission level in the city center by excluding vehicles emitting high CO2 emissions. The standard both for small and large vans with petrol engines at least Euro 4 and diesel with Euro 6 allows access to the ULEZ even after the period of 25 October 2021. However, the government's target is to ban diesel, gasoline and hybrid electric vehicles after 2025 in the city center. While the penalty fee is different for small vans requiring to pay £12.5 and for larger vans the charge is £100 if the standards based on Euro level do not meet.

## 3.2 Economic Factors:

### 3.2.1 Incentives and Tax Benefits for Alternative Powertrains in EU

As the European Union has implemented new average emission level measures based on the regulations for vehicle manufacturers, almost all of them have been developing their own emission reduction technologies such as hybrid or fuel cell electric vehicle types and ,especially having the higher emission levels like German manufacturers, most of them focusing on BEVs deployment instead of paying large amount of fines or missing the opportunities to develop their strategies with benefits granted by the governments or the local municipalities.

**California**: The Zero Emission Vehicle program has been introduced to keep under control GHG emissions in California by requiring the vehicle manufacturers to sell specific numbers of zero/low emission vehicles including the battery electric, plug-in-hybrid and fuel cell electric vehicles. The California Air Resources Board (CARB) adopted the Advanced Clean Cars program by regulating their standards in a long-term and more severe way to reach the goal of a total 10% ZEV of new vehicle sales by 2025 [27]. Their estimations show that 15% of new vehicle registration will be zero/low emission vehicle types in California to meet the ZEV requirements. Recently, the California government signed an agreement to ban the sales of new gasoline cars by 2035.

**China**: Regarding recent analysis, China has the world's largest electric vehicle industry as well as the only leader producing 99% of electric buses globally. As their introduction to the Europe vans market with new Chinese brands and collaborations for battery production and developments of electric vehicles, its dominance in EVs will be more perceived during the next couple of years in the EU LCV market. However, behind this advancement, there was also an industry plan introduced in 2010 with a target of selling 1 million electric vehicles until 2015. Ministry of Industry and Information Technology in China concluded its policy requirement, New Energy Vehicle (NEV), in 2017 similar to California's NEV mandate in order to stimulate the production and sales of battery electric vehicles, plug-in hybrids including range extender electric vehicles and fuel cell electric vehicles for the period between 2021 and 2035. According to this policy, annual production or import volume of conventional passenger cars cannot exceed the 30,000 units threshold while there are vehicle credits for BEV, PHEV and FCEV based on the electric range [28].

Similarly, European Parliament is keen to implement new sanctions that require the automobile manufacturers to sell EVs quotas with a limit like a recent trend in the United States and China after 2025, however, this requirement strongly depends on the financial incentives and tax benefits provided by government policies.

All around the world, governments have been establishing their laws and policies in terms of providing a bonus ranging between different financial incentives and tax exemption benefits for switching the electric mobility in order to decrease GHG emissions locally and minimize the dependence of the transport sector on combustion of fuels releasing toxic air pollutants. As the benefits vary from country to country, the information about the financial incentives has been collected for the EU member states with the highest total number of LCVs in circulation on their roads in 2018, exceeding the threshold of 2 million units. Accordıng to data published by ACEA, France(6,233,473), Spain(4,640,154), United Kingdom(4,407,561) and Italy(4,146,206) are the biggest LCV markets over 4 million vans on their roads for each country, followed by Germany and Poland with over 2.7 million and 2.6 million registered total number respectively [11]. Other EU member states selected to examine government policies are Netherlands (995,796), Belgium (769,386) and Denmark (389,350).

- **France**

The French government declared its climate plan to ban the sales of internal combustion engine vehicles by 2040 and a more ambitious roadmap has announced that more than 100,000 charging infrastructure will be accessible by 2021 by producing over 1 million electric vehicles annually until 2025 with a €8 billion budget [29].

There are two different bonus systems that the first one is ecological bonus containing purchase subsidies and another called Trade-in bonus valid for passenger cars is based on scrappage systems including diesel vehicles older than 2001 and gasoline powered vehicles produced before 1997 changing them with a new battery electric or plug-in-hybrid vehicle. Different car manufacturers have reached an agreement to share a precise amount of cost for older vehicles for scrapping [30].

Purchasing Subsidies: Light commercial vehicles emitting less than 20 g CO2 /km and having purchase price under €45,000 are eligible to receive an incentive as an amount of 27% of the purchasing cost including tax, up to €7,000 until the end of 2020, €6000 in 2021 and reducing to €5000 in 2022. Vans having prices between €45000 and €60000 receive a benefit of €3000 while if it is more expensive than €60000, €3000 grant can be obtained.

For plug-in-hybrid vans emitting between 21g and 50g CO2/km and having 50 km pure electric range with a price not higher than €50000 can receive €2000 bonus in 2020 and reducing to €1000 in 2021. Trade-in Bonus with scrapping is valid for cars.

Tax benefits: There are 50% subsidies or full exempt on registration tax both for battery electric and plug-in hybrid vehicles.

Local incentives: Electric vehicles can be parked freely up to 2 hours depending on the region.

Charging infrastructure benefits: For the residential area, there is 50% of subsidies, up to €500 for every charge point while for public regions 50% of subsidies excluding tax up to €4000 is available [31].

- **Spain**

In the mid-June of 2020, two new programs have been announced, namely MOVES II (until waiting for official publication) and Renove, that Spain government introduced with a budget of over €650 million for automotive industry by sharing 100 million euros for the MOVES II which is a grant for the sales of zero/low emission vehicles depending on pure electric range and Renove program which offers an incentive discount on purchase of new or pre-owned cars in order to increase clean fuel vehicles deployment . Renove Program will continue until 31st December 2020 and total budget of €250-million will be divided into vehicle type as only 10% will be used for light commercial vehicles. [32]

Purchasing Subsidies: According to MOVES II plan published on 16 June 2020, LCVs with more than 30 km pure electric range can receive a grant of €4400 or if a vehicle is scrapped it can increase to €6000 for private customers. The small & medium-sized companies having light commercial vehicles with 30 km or more electric range can utilize €3630 subsidy or €5000 for the scrapping solution while these benefits are €2900 and €4000 depending on with or without scrappage for big businesses.

On the other hand, Renove grants are separated for LCVs depending on gross vehicle weight in two parts; one less than 2.5 tones; others higher than 2.5 tones.

- Private customers : LCVs having less than 2.5 tones present benefits of €4000 for vans with more than 40 km battery range and for LCVs up to 40 km electric driving the grant is €1200; more than 2.5 tones having the same benefit system with €4000 and €2700, respectively.
- Small-medium size businesses: LCVs<2.5 tones having more than 40 km electric range receive a grant of €3200 and less than 40 km can offer €950 while for one>2.5 tones has €3200 and €2200 benefits depending on range threshold 40 km.
- Big Businesses: The heaviest total weight of vans lower than 2,5 tones can receive up to €2800 for which having 40 km pure electric range at least or €850 for electrified vans having less than 40 km electric driving range,

MOVES II;

- Private customers: The grant changes depending on scrapping the old car receiving €5500, otherwise, it is €4000.
- Small businesses: LCVs with maximum technically permissible laden mass up to 3.5 tones and 30 km or more electric range are eligible to utilize €5000 if the old van is scrapped otherwise, the grant is €3630.
- Big businesses: LCVs up to 3.5 tones driving at least 30 km electric range are able to receive €4000 with scrapping solution or up to €2900 without exchanging old vehicles.

Tax benefits: The grants for ownership tax vary depending on regional policies. There is no registration tax for BEVs.

Local incentives: Most cities allow EV vans to use reserved parking, traffic lanes and toll highways freely.

Charging infrastructure benefits: According to MOVES II plan, there are grants for private customers and businesses up to 40% of total cost of purchase and installation of private and public charging points with a total amount up to €100,000 [30] [31].

- **United Kingdom**

In 2018, an agreement has been reached for the ban on the sales of new internal combustion engine vehicles in the U.K. by 2040 but, according to fresh news, the Transport ministry has discussed bringing the deadline to an earlier date. Also, in order to increase the sustainability of ultra-low emission fuels and to improve the economic growth by following more ambitious strategy to obtain the leadership position in low emission vehicle technology as they leave the European Union, country initiated a series of different plans both on the Office for Low/Zero Emission Vehicles (OLEV) with over £900 million budget and electrification roadmap beyond 2020, called Road to Zero [33].

Purchase subsidies: As all the data for light commercial vehicles by brand which are eligible for EV grants available on the UK government websites, light commercial vehicles having CO2 emission level less than 75 g/km as well as having 16 km pure electric range at least can receive a discount of 20% on purchase price provided that incentive amount that do not exceed limit of £8000 (£20,000 for the first 200 orders for large electric van) with the name of bonus, Plug-in grant.

Tax benefits: There is no registration and annual ownership tax for BEVs costing up to £40,000 since 2017 and vans with a limited electric range pay less registration tax than conventional vans. There will be a nil rate of tax for battery electric vans starting from 2021.

Local incentives: Even though there are some discounts and free parking areas in different regions, the U.K. government has been preparing to assign green number plates for electric vehicles in order to allow these vehicles to use other local benefits.

Charging infrastructure benefits: Electric Vehicle Home Charge Scheme offers a bonus up to 75% for the costs of purchase and installation for a domestic electric vehicle charger point, capped at £350 including VAT. According to Workplace Charging Scheme, businesses and public organizations are supported with a grant up to 75% of all cost of purchase and installation of EV chargers with a maximum limit of £350 for each socket [30] [31].

- **Italy**

Italy has initiated a new program 'eco-bonus' in the middle of the 2019 and has invested 70 million Euros to increase the purchase incentives for the vehicles emitting $CO_2$ emissions up to 60 g/km and the grants of charging infrastructure. Between the period of 1st of August and 31st of December 2020, incentives have been increased temporarily on the condition that the list price of electric and hybrid vehicles do not exceed €61,000 in order to invigorate the economy after Covid-19 lockdown. Also, in case of public administrations deciding to renew their fleets, the share of all fleets has to be 50% of electric, hybrid or hydrogen vehicles for the purchase or rental activities.

Purchase Subsidies: The amounts of incentives are determined based on the scrapping of a van with European emission level from Euro0 to Euro Euro4:

- With scrapping: Incentive of €6,000 for the vans having $CO_2$ emissions up to 20 g/km (increased to 10,000 euros for the post-lockdown period) and 2,500 euros for the vans emitting $CO_2$ emissions between 21 and 60 g/km.
- Without scrapping: 4,000 euros incentive for the vans having $CO_2$ emissions up to 20 g/km (increased to 6000 euros for the post-lockdown period) and 1,500 euros for the vans emitting $CO_2$ emissions between 21 and 60 g/km.

Tax Benefits: There is no annual ownership tax for the first five years from purchasing both for BEVs and PHEV/REEVs. After this period, the tax rate will be cut 75% by taking into account its equivalent petrol vehicles.

Local incentives: Hybrid or electric vehicles are able to have free access in ZTL (Limited Traffic Zones) and free parking.

Charging infrastructure benefits: Companies and individuals installing EV charging infrastructure between 3.7 kW and 22 kW can receive a tax reduction of 110% of the purchase and installation up to 3,000 € until 31 December 2021 [30] [31].

- **Germany**

Germany is one of the best countries with the ambitious objective to increase electric vehicle adoption by extending their incentives for purchase subsidies, tax reductions, charging infrastructures and so on. German government has a plan to see on their roads at least 10 million electric vehicles with supplying up to 1 million charging stations by 2030 as regarding the 2030 Climate Action Program and recently they have initiated different kinds of bonuses to stimulate the electric vehicle deployment, namely Post-Covid-19 package with €130 billion. In addition, the government has announced that social services will receive a fund in order to shape their fleets with electrified vehicles with overall €200 million and they are obligated to install electric vehicle charging stations in every petrol station until the end of 2021. Generally purchase incentives are shared between German government and automotive manufacturers equally to reduce CO2 emission levels both as following a win-win strategy.

Purchase subsidies: Between the June 2020 and 31st December of 2021, vehicles with a net list price up to €40,000 can receive a subsidy of €9000 for BEVs and €6750 for plug-in hybrids while for vehicles having price between 40,000 and 65,000 euros are eligible to take a bonus of €7500 for BEVs and €5625 for plug-in hybrids. Another benefits initiated by the government as Umweltbonus (Environmental bonus) program finished at first July of 2020, were one third less with respect to previous incentives. An important point for the plug-in hybrids to be able to utilize the bonus, until 31st of December 2021, is to have a characteristic of minimum electric driving range of 40 km or emitting up to 50g CO2/km. Then this range will have to reach 60 km and 80 km at least in 2022 and 2025, respectively.

Also, scrapping systems can be applied to used-cars older than 12 months with higher than 15000 km mileage can receive up to €5000 for BEVs or FCEVs and €3750 for plug-in hybrids as they do not participate in Environmental bonus.

Tax benefits: Battery electric vehicles or fuel-cell electric vehicles registered between 2016 and 2025 have a 10-year exemption from motor vehicle tax . After this period, cost of tax will be determined based on the vehicle gross vehicle weight with half of €11.25 up to 2000 kg, €12.02 up to 3000 kg and €12.78 up to 3500 kg. On the other hand, there will be tax exemption lower than diesel or petrol vehicles to be paid for plug-in hybrids depending on the CO2 emission level.

Local Incentives: Battery electric vehicles are able to have free access to reserved bus lanes and parking slots.

Charging infrastructure benefits: As the charging infrastructure benefits are changing depending on the region policies and funds, government has almost €2.5 billion budget to increase the development of EV charging accesses by constructing private charging points with €500 million and research and development costs with the same amount of fund while the remaining €1.5 billion will be financed for the establishment of a battery cell production plant. The Federal Ministry of Transport and Digital Infrastructure has initiated series of public charging benefits depending on the station type in order to achieve having 1 million charging stations in Germany by giving up to €3000 incentives for charging points between power of 0 ad 22 kW, up to €12,000 for DC chargers with maximum 100 kW power, up to

€30,000 with power more than 100 kW and lastly, bonus of €5,000 and €50,000 granted up for low voltage and medium voltage grid connections [30] [31].

- **Netherlands**

Dutch government is so successful in having steady progress in the number of EV charging points per 100 km with the ratio of 19.3 being the top country in this field worldwide. The total budget for the EVs deployment in the country is €17.2 million including the period between 2020 and 2025, as the budget of the new BEVs is €2.8 million higher than other grants for the used electric vehicles. Netherlands has its electrification plan by allowing only zero emission vehicles to be registered in the country beyond 2030 and diesel and/or petrol-powered vehicles have to pay tax more by one cent per liter in 2020 then another penalty of one cent per liter will be added in 2023 [34].

Purchase subsidies: Starting from July 2020, depending on the electric vehicle conditions that of having a pure electric range 120 km at least and list price between €12,000 and €45,000 registered after 4th of July 2020, there are different subsidies for the vehicle up to €4000 for purchasing or the leasing a new EVs while the amount is €2000 for a used vehicles in the conditions that they have to be produced as a pure electric vehicle and being purchased by a dealer. Fuel cell electric vehicles are not eligible for this type of grant.

Tax benefits: There is fully exemption for battery electric vehicles both on purchase and ownership tax until 2024 then fully EVs have to pay only 25% of tax while plug-in hybrids are eligible to receive 50% reduction until 2024 on ownership tax and a reduction on purchase tax depending on the quantity of co2 emissions, after 2025 they have to pay 75% of the ownership tax. On the other hand, 12 years or older vehicles exceeding a certain level of CO2 emission have to pay 15% more on 2019 ownership tax amount.

Charging infrastructure benefits: In Netherlands, EV user can ask the public agencies for EV charging installation to have easy access near their homes or workplace so there is no known incentive available for the purchase of EV charging infrastructures. [30] [31]

- **Belgium**

The capital of Europe, Brussels, will initiate a plan to ban diesel and petrol-LPG vehicles by 2030 and 2035 respectively as well as preparing a ban of motorcycles emitting high levels of CO2 by 2022. Country has focused on tax benefits in order to promote electric vehicle sales while in the northern half of Belgium, Flanders, a purchase subsidy started in 2016 with up to €4000 of benefit for battery electric and fuel cell vans but it was available until the end of 2019.

Purchase subsidy: There is a grant of 20% on purchase price for non-diesel LCVs up to €3,000 in Brussels dedicated for micro/small companies having to change their diesel van by reason of LEZ restrictions.

Tax benefits: BEVs and plug-in hybrids emitting CO2 less than 50 g/km do not have to pay registration and ownership tax until 2020 in Flanders while battery electric vehicles pay minimum amount of €61,5 and €83,56 (instead of paying €1,900) for registration and annual registration tax. There is no company tax for vehicles emitting less than 42 g CO2/km.

Charging infrastructure benefits: Businesses registered to the corporate tax system are able to utilize 13.5% deduction on installation of charging infrastructure. There is a tax exemption up to €75 for the companies which use parking spaces for charging units [30] [31].

- **Denmark**

As the Danish government initiated ambitious climate targets to cut fossil fuels out of the country by 2050, The Danish Energy Agency has been providing incentives to local administrations and companies for the EVs development and market penetration since 2013. Also, the six largest cities of Denmark committed for the transition of electric buses for all over fleets.

Purchase subsidies: Currently there are no purchase incentives for e-LCVs in Denmark.

Tax benefits: The amount of taxes are determined by taking into account the vehicle fuel consumption and weight so fully electric vehicles and plug-in hybrids pay less than conventional diesel and/or petrol vehicles. Registration tax for EVs decreased by 80% in 2020 and there will be a 65% discount on tax in 2021, it will be reduced gradually to take 10% of fully registration tax in 2022, %100 in 2023.

Local incentives: Electric cars do not pay parking fees in case of not exceeding DKK 5000 (670 €) per year.

Infrastructure benefits: There is a tax exemption for commercial charging [30] [31].

## 3.3 Social Factors:

### 3.3.1 Consumers' Needs and Concerns regarding to e-LCVs

Beyond the motivation of meeting CO2 emission fleet-wide targets in EU, there is an upward trend of transition to an e-LCV fleet among the van manufacturers because of the reasons that cost the batteries is expected to decrease dramatically from as today battery price has a share of approximately 60% to below 25% of the total cost of the electric vehicle within 5 years and advance level of competition between the OEMs to obtain a pole position in the e-LCV market as soon as possible by receiving government grants and incentives for the production and sales of the low/zero emission vans. As the electric vehicles market shows a significant increase in its volume, especially in the last 6 years, and as also it seems to be more preferred by customers in the LCVs market thanks to lower fuel cost, less servicing cost with fewer moving components with respect to diesel or petrol vans, incentives granted by the EU countries and discouragements and bans of ICE vehicles in access of city centers or in countries depending on their governments' policies to reduce the emission and noise level in a short span of time, the price difference between battery electric vehicles and conventional vehicles is getting smaller as the manufacturers focus on their attention to invest alternative zero/low emission vehicle powertrain technologies so the costs of higher electric vehicles components will predictably go down in next demi-decade. In order to reduce the average emissions of their fleets and to play an active role in the upward trend of electricity, LCV manufacturers have launched numerous new models in recent years in Europe. On the other hand, according to a survey of Arthur D. Little that is made with the participation of fleet managers, result shows that one third of survey participants have declared their willing to buy an e-LCV in near future and their main motivations are firstly their low emissions emitting in environment and then the advantage proved by total cost of ownership and lastly financial incentives that are granted by governments as an encouragement [35] but oppositely, there are serious barriers for electric vans that OEMs have to tackle with as following;

**Range anxiety**: Limited range of electric vans can be considered as the fundamental negative effect for purchase decisions because private customers or fleet operators have hesitation in reaching desired daily ranges without waiting for longer charging times by using e-LCVs. However, driver's concern about the shorter driving range need to be relieved to make e-LCVs more attractive for sale against its main competitor diesel-powered van with the developments of battery technology and constructing relevant charging infrastructures. In current LCV market of large segment, despite the heavy chassis structure and battery packs, as an example, Fiat Ducato with battery capacity of 47 and 79 kWh is able to reach the driving range of 220 and 360 km of NEDC respectively depending on the weather conditions with reference to L2H1 version [36] .

**Lack of EV charging stations**: Despite the increase in the new registration number of electric vehicles in the recent years, charging network growth is not able to show the same attitude to supply sufficient infrastructure over Europe even the vast majority of the countries have been granting the installation of EV charging infrastructures to private customers and businesses. According to ACEA report, the distribution of the EV charging points have been gathered in 3 EU countries, coming Netherlands as having advanced organized EV charging point number with 25.4% of all Europe if it is taken into account that total new registration number of EVs is less than other EU members with more than 70.000 units in 2019, followed by Germany with almost 39.000 new charging units and 105k passenger cars and almost 20k e-LCVs in 2019 so German roads still need to be equipped with more charging points in spite of its high volume EV deployment in the country [13]. Similarly, even though France is the third country of having the highest number of EV charging infrastructure over 29k units, they still remain incapable to serve the EV drivers with total number of 61k for vans and 48k for passenger cars so that customer’s decision on buying a new electric vans can be changed probably by a lack of charging point near to domestic or workplace [37].

**Charging time**: Another key consideration of electric vans for potential customers is how long they have to wait to fully charge the vehicle battery. Depending on the potency and type of the charger, charging time differs as follows; wall plug with 2.3 kW can recharge the battery to full in around 16 hours while 1-phase (3.7 kW) and 3-phase (3.7 kW) used in different countries can charge the Renault Kangoo Z.E. within 5 hours. While large segment of VW e-Crafter with 35,8 kWh battery capacity can be fully charged depending on charging station power as indicated in the table:

| **Charging Power** | Charging Station (7,4 kW) | Charging Station (4,6 kW) | Charging Station (3,7 kW) | Domestic Socket (2,3 kW) | Combined Charging System (40 kW DC) |
|---|---|---|---|---|---|
| **Charging time** | 5,5 h | 8 h | 10 h | 17 h | 45 min (80%) |

**Table 7 – Renault Kangoo Z.E. Charging times with different EV charging types [38]**

**Purchase cost**: Despite the running costs of e-LCVs in terms of cost of fuel/energy consumption, maintenance and taxations are lower than diesel alternatives; there is still a huge difference in price between electric vehicles and equivalent conventional one that puts the expensive e-LCVs at a disadvantage to be selectable by consumers. For instance, Mercedes Vito with diesel-powered engine has a price starting from €26.000 while the same segment of e-Vito has a list price of over €58.000 in Italy [39]. Nevertheless, lithium-ion which is the commonly used for battery, is made out of either nickel cobalt aluminum or nickel manganese cobalt oxides which determine the battery capacity and the price of electric vehicle depends on battery capacity per kilowatt hour so that cost of battery has been going down corresponding to finding new mines. According to a report published by BloombergNEF, the average price of battery of a passenger car per kWh has dropped below $160 in 2019 while it was more than $1160 in 2010 and it is predicted that the average price will decrease below $100 until 2024. In conclusion, purchase price of the electric vans will be decreased in parallel with the advancement of battery technology and resources [40].

**Residual value**: The depreciation rates of the electric vehicles have a tendency to decrease more rapidly than equivalent conventional vans as there is an uncertainty in the e-LCV market so that the remaining value as a percentage of the purchase price is much less for the second or the third end-user. Even though lithium-ion batteries are maintenance free, most of the manufacturers offer an 8-year warranty to compensate for the rapid drop residual value of electric vans along with battery performance after a certain time.

**Less payload capability**: Due to the battery packs covering a large amount of area, it is obvious that maximum payload of the electric vans is not able to compete with equivalent diesel-or-petrol-powered vans in terms of carrying weights, nowness. On the current market, for an example, Renault Kangoo Z.E. has a maximum payload of 640 kg while its diesel-powered equivalent is capable of carrying up to 782 kg, as the cargo volumes are the same both for electric and conventional powertrains ranging from 3 to 4.6 m3 in the compact segment. On the other hand, other rivals are coming with more generous offers, like Chinese Maxus eDeliver 3, in terms of higher maximum payload with 865-905 depending on the battery pack and volume of 4.8 m3.

**Decreasing in battery performance depending on several conditions over time**: Another concern about the electric vans is the fast battery discharge in a short time or limited range depending on the driving and weather conditions, quantity of good to be carried, number of passengers or using auxiliary components so the efficiency of the battery is highly affected by external factors. For instance, the old version of

Citroen e-Berlingo consumes 124 Wh/km in city cycle during mild weather while its range decreases as the temperature is getting cold to 186 Wh/km [38]. Therefore, advancement in electric vehicle technology has been studied to improve driving cost and performance of energy storage systems, electric machines and power electronics in the propulsion world.

### 3.3.2 Consumer Concerns regarding to BEVs Adoption by EU member states

According to Deloitte Global Auto Consumer Study, different sentiments from the customers' point of view in terms of purchasing a new BEV with swapping its equivalent ICE are presented for some EU member states (considering UK as well) from the period of 2018 to 2020. The table shows that main barriers for EV adoption are the limited driving range and insufficient charging points for four countries. However, there is no change in consumer concerns in terms of range anxiety for German drivers within two years, similarly, Italian citizens are in hesitation to buy a new electric vehicle because of lack of charging infrastructure in their cities for two years but now, most of them, also, contemplate on short driving range. Oppositely, even new registration numbers of electric vehicles have been increased in the U.K. from 2018 to 2020; English drivers suffer from insufficient availability of EV public charging. The top concern changed among the French vehicles' users from cost/price Premium to driving range [41].

| Main Concerns regarding to BEVs | France | | Germany | | Italy | | UK | |
|---|---|---|---|---|---|---|---|---|
| | 2018 | 2020 | 2018 | 2020 | 2018 | 2020 | 2018 | 2020 |
| Driving range | 31 | 28 | 35 | 33 | 4 | 27 | 26 | 22 |
| Cost/price premium | 32 | 22 | 22 | 15 | 19 | 13 | 24 | 16 |
| Charging time | 11 | 15 | 11 | 14 | 18 | 16 | 13 | 16 |
| Lack of charging infrastructure | 16 | 22 | 20 | 25 | 44 | 32 | 22 | 33 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Safety concerns with battery technology | 4 | 11 | 5 | 10 | 7 | 10 | 6 | 12 |
| Others | 6 | 2 | 7 | 3 | 8 | 2 | 9 | 1 |

**Table 8 – Main Concerns regarding to BEVs in 4 different countries**

## 3.4 Technological Factors:

### 3.4.1 Technological Developments beyond 2020

Three main components that are electric energy storage element, electric motor and power electronic converter are included both for BEV and HEV system architecture. In this section, rising trends in battery innovation, electric machines and power electronics improvements that allow to find the best trade-off between cost and performance in the mass-market are explained. On the other hand, developments in thermal propulsion systems of ICE vehicles have been focused on the purpose of increasing both thermal and systems efficiency with the combination of hybrid technology.

**Advanced Energy Storage Technologies**: Vehicle battery composed of putting together cells, modules and packs that a group of cells form the a module, consecutively, a pack is composed of a cluster of modules and behind the working principle of a battery, there is potential difference created by electron circulation between negative (anode) and positive electrodes (cathode) that are included in conductive ionic liquid calling electrolyte and separated by polymeric separator to avoid short circuit. When the battery is discharging, electrons excessed in anode start flowing to the cathode through external load. Mostly used battery types for LCVs are Lithium-ion and lithium-polymer thanks to its cost-energy density-weight sensitivity while lead-acid and nickel types of batteries have been used rarely. However, strategic characteristics for batteries of light duty vehicles are dependent on high energy density-low cost for larger capacities widely and of increased power-sensible price. In the following, energy storage technologies separating into battery components are expressed beyond 2020:

In the short term, graphite in anode with silicon metal is able to increase energy density of batteries and progressively it can be replaced with 100% silicon in the next future. On the other hand, Lithium Iron Phosphate materials can be used in order to reduce cost for the cathode material while higher power density can be obtained with the mix of nickel, manganese, and cobalt. Lithium-Nickel-Manganese-Cobalt-Oxide ($LiNiMnCoO_2$), called as NMC, for cathode side. Also, research on sodium-ion, Li-S and metal air materials has been focused to supply higher voltage between cathode and anode. Lastly, separators are specialized with better oxidation resistance and heat dissipation to provide fire protection [10].

**Electric Machine Trends**: Electric machines as an essential component of electric vehicle powertrains are utilized for traction purposes by requiring high efficiency, high start-up torque and fast torque response with high power density and specific power. In the most recent automotive applications, there are permanent magnet synchronous machines, switched reluctance motors and inductions machines that are highly used. The basic principle both for synchronous and asynchronous machines is based on the relation between motor moving parts, rotor, with a rotating magnetic induction field generated by stator windings. A permanent magnet is free to rotate around the axis orthogonal to magnetic induction field, torque arises between induction field and coil (permanent magnet).

By 2030, improved motor architectures with transverse flux or high speed synchronous motors and new machine design with additive layer manufacturing will be possible for the electric machine market. Moreover, electric machine winding formed by laminated magnetic core or litz wire is possible to be used in near future like electrical steels for magnetic cores [10].

**Power Electronic Converters**: they are used to generate three-phase current excitations needed for the operation of electric motors that connect to either positive or to negative terminal of battery, including three-phase converter and electronic control unit. Power MOSFET and bipolar junction transistors are the most used power electronic converters in automotive applications. There are significant studies on ultra-wide band gap SiC and GaN semiconductors with new packaging designs and sensorless, self-learning optimized software for converters [10].

**Thermal Propulsion Systems**: As today average brake thermal efficiency is almost 42%, estimations based on the advancements in thermal powertrain show that 48% of efficiency can be reached within 5 years. Even though most countries announced the intention of bans on diesel and petrol vehicles, they are convinced to allow the existence of internal combustion engines with hybrid and PHEV/REEVs as long as these vehicles guarantee limited pure electric range. In this term, recent combustion technologies to obtain more efficient combustion such as water injection, flexible variable valve actuation with downsized engines or with diesel/petrol after-treatment systems like DPF, lean NOx trap, three-way catalyst work in progress for the improvement of efficiency and reduction of pollutant emissions with different hybridization types and integration of multi-speed gearbox [10].

**Light-weighting Technology Developments**: Depending on the ambition to reduce vehicle weight both for conventional and electric vehicles, their estimated changes based on vehicle weights in 2020 are shown in the table:

| Year | 2025 | | 2035 | |
|---|---|---|---|---|
| Ambition level | Standard | High | Standard | High |
| Conventional vehicle | 5-10% | 10-15% | 20-25% | 30-35% |
| Electric vehicle | 10-15% | 20-30% | 15-20% | 30-40% |

**Table 9 – Vehicle weight reduction estimations [10]**

### 3.4.2 New e-LCVs beyond 2020

So as to better understand what is going on the current market and how it can be changed in near future, some new electric vans that are introduced or announced to enter in the mass-market are illustrated as an example below:

- **Daimler**

Instead of paying fines of millions of euros because of its higher emission level of LCV fleet, Mercedes-Benz Vans invested two billion euros in order to enlarge and develop their product portfolio, especially for pickup and large segments of Sprinter, in 2017, meanwhile, a commercial van strategic initiative, namely Mercedes-Benz adVANce, has been introduced in order to better connect services such as rental of vehicles, sharing innovative solutions and support of electric and autonomous systems [39]. Recently, the company launched a new plan to construct a platform, the Electric Versatility Platform (EVP) for the production of large segment electric version, Sprinter, with a total of €350 million investment as a part of its electrification deployment strategy. On the other hand, they signed an agreement with CATL, China's largest battery producer, to develop battery technologies. In addition to vans indicated in the table, Daimler announced that its small van Mercedes Citan will be produced with fully electric powertrain by the partnership of Renault-Nissan-Mitsubishi [42]. Although it is able to retain its battery capacity up to 70% after 8 years, like all battery electric vans, e-Sprinter leaves less capacity of payload with respect to equivalent large diesel vans [43].

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Mercedes e-Vito (2020) | Midsize van | 180 - 421 km (NEDC) | 35-90 | 6&10 | 1026-775 | 6 | 85-150 |
| Mercedes e-Sprinter (2020) | Large van | 102 - 158 km (WLTP) | 35 - 47 | 8 | 900 | 11 | 85 |

**Table 10 - Mercedes e-LCVs characteristics**

- **FIAT**

Apart from its agreement to merge 50:50 with PSA Group, as corporate name Stellantis, for the passenger car market, FCA has a roadmap to offer 30 electrified powertrain types at least by 2022. On the other hand, Fiat Professional produced its first large segment LCV, Fiat e-Ducato, with different battery capacities (three modules with 47 kWh and five modules with 79 kWh) to develop its customer portfolio and present different payloads by offering the best volumes between 10 and 17 m3 in the LCV market. During the design phase of e-Ducato, all typical van's driver behaviors, load, environmental and road conditions have been analyzed to better reflect the electric powertrain performance to make it more competitive against equivalent conventional van characteristics by offering fuel efficiency and low total cost of ownership advantages [44]. Recently, Fiat Panda Van has been renewed as a mild-hybrid with 1.0 liter 3-cylinder petrol engine in 2020.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Fiat Panda Van Mild-Hybrid (2020) | Car-derived van | - | 0,13 | - | 935 | 1 | 3,6 |
| Fiat e-Ducato (2020) | Large van | 220-360 km (NEDC) | 47 & 79 | 7.5 & 8 | 1950 | 10 & 17 | 90 |

**Table 11 - Fiat Professional e-LCVs characteristics**

- **Ford**

Ford has revealed his plan on electrification of its LCV fleet for all future commercial vehicles with an investment amount of $11 billion to e-LCV platform within 5 years by transiting from internal combustion engines to hybrid vehicles and different types of electric powertrains like its petrol-powered range extender Ford Transit Custom. UK's largest manufacturer Ford collaborate with Volkswagen in order to produce Ford electric vehicles in different segment such as pickup engineered by Ford, based on VW Amarok, a compact model with advancements of VW Caddy and a cargo van which is one-ton unit by 2023 on VW's Modular Electric Drive (MEB) as well as they will build a partnership with German Deutsche Post DHL to produce electric delivery vans, StreetScooter WORK XL [45]. The table illustrates the first LCV produced with plug-in hybrid technology, Ford Transit Custom PHEV, having 56 km pure electric range with 13.6 kWh battery combined with 1.0-litre petrol engine range extender while American multinational company has been preparing to offer its large segment van in 2022. Also, DHL company offers its electric van Street Scooter produced by Ford, with an average 6 hours charging time.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Ford Transit Custom PHEV (2019) | Midsize van | 56 km (NEDC) | 13.6 | 4.3 | 1130 | 6 | 92.9 |
| Ford e-Transit (2022) | Large van | 350 km (WLTP) | 67 | 12 | 1616 | 15.1 | 198 |
| StreetScooter (2019) | Midsize van | 187 km (NEDC) | 40 | 4,5 - 7 | 905 | 8 | 48 |

**Table 12 – Ford e-LCV characteristics**

- **Iveco**

Italian company designed its first electric commercial vehicle, Daily Electric, in 1986. Because of its high CO2 emission level of heavy duty vans in Europe, they are preparing to renew its powertrain ranges with low/zero emission LCV types to follow electrification trend in LCV sector, in the same time, Italian manufacturer has been investing on servitization and connectivity for customer's profitability and digitalization offering driver assistance systems and advanced driver's safety [46].

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Iveco Daily Electric | Large van | 280 km (NEDC) | 28,2 | 10 | 1652 | 7.3-19 | 80 |

**Table 13 - Iveco e-LCV characteristics**

- **PSA**

Group PSA introduced to the e-LCV market their midsize van models, Peugeot Expert and Citroen Dispatch (by producing also Vauxhall Vivaro and Toyota Proace with badge engineering) and offers large segment electric vans, Peugeot Boxer and Citroen Relay (produced in Atessa in southern Italy with collaboration of two groups Fiat and PSA) before 2020 and they are preparing to launch their new electric versions of compact segment with the new Peugeot e-Partner, Citroen e-Berlingo, Opel Combo and Vauxhall Combo-e in order to complete their LCV fleets with electrified portfolio in all segments before the end of 2021. On the other hand, French manufacturer has been preparing to transform their fleet as all-electrified for all vans until 2025 [47].

Their production plants for the integration of powertrain components of the upcoming compact vans on eCMP (Common Modular Platform) platform are located in different countries, for assembly in Spain and electric motors will be manufactured in Tremery, France and similarly transmission components in Valenciennes, France. Additionally, another PSA platform, Efficient Modular Platform (EMP2) has been used for other LCV and passenger car models that will be offered with fifteen new electrified vehicles until 2021, composed of 7 plug-in hybrid as well as mild-hybrid electric vehicles and 7 new battery electric vehicles. It is shown on the table that Peugeot made a huge progress with its compact van, newly e-Partner, by increasing driving range even though it is an estimated data. Group PSA is ready for the electrification of its fleet in order to race to the top in the e-LCV market.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Peugeot Tepee Electric (2017-2020) | Compact van | 170 km (WLTP) | 20,5 | 6h45m | 571 | 5 | 49 |
| Peugeot e-Partner (2021) | Compact van | 240 km (predicted) | 50 | N.A. | N.A. | N.A. | 100 |
| Peugeot e-Expert (2020) | Medium van | 230-330 km (WLTP) | 50-75 | 7,5 | 1275 | 6,6 | 100 |
| Peugeot e-Boxer (2021) | Large van | 225-270 km (NEDC) | 37-70 | 5 & 9 | 1890 | 8 & 17 | 90 |

**Table 14 - PSA e-LCVs characteristics**

- **Renault-Nissan-Mitsubishi**

Even though there are other brands with alliance of French and Japanese manufacturers, Renault-Nissan-Mitsubishi, they have been leading the battery electric vehicle market over the last years both in the passenger and van EU market. The Common Module Family (CMF), similar to VW's MQB, is the modular platform including engine compartment, cockpit, front and rear underbody and electric electronics with the alliance of Chinese Dongfeng for the production activities. The alliance has a plan to sell 1 million electric vehicles per year with 12 new battery electric vehicles that will be added on their fleets with an investment of $1 billion within the five years. The partnership reached a total number of over 540.000 electric vehicles sold in 2017 and Groupe Renault says that one fourth of vehicles sold in Europe carry its brand and they have a wide range of electric commercial vehicles in their fleet, for example, ZOE Van that is the smallest electric van with 52 kWh battery and Europe's top-selling electric commercial vehicle Kangoo Z.E. which has released for retail sales in 2011 and Renault Master Z.E. with a 33 kWh battery and 120 km real-world driving range are e-LCVs in Renault fleet [48]. As it can be seen from the table presenting Renault electric vans, car-derived model Zoe has a noteworthy driving range based on WLTP with demanding 3 hours charging time. On the other hand, despite Kangoo electric model being able to run 230 km with a fully charged condition, it offers almost 200 kg less payload with respect to equivalent diesel vans.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Renault Zoe Van (2020) | Car-derived van | 395 km (WLTP) | 52 | 3 | 457 | 1 | 80 |
| Renault Kangoo Z.E. 33 (2020) | Compact van | 230 km (WLTP) | 33 | 6 | 605 | 4 | 44 |
| Renault Master ZE (2020) | Large van | 130 km (WLTP) | 33 | 6 | 1490 & 970 | 8 & 13 | 57 |

**Table 15 – Renault e-LCV characteristics**

Also, Nissan offers its medium segment commercial vehicle, e-NV200, with 100% electric firstly released in 2014 as well as Mitsubishi developed its Outlander as PHEV commercial van that has a short pure electric range with 2.0 gasoline engine as it is one of the top-selling vehicle in alternative fuel passenger car market.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Nissan e-NV200 Evalia (2019) | Small van | 200 km (WLTP) | 40 | 7.5 | 705 | 3 | 80 |
| Mitsubishi Outlander PHEV (2020) | Midsize van | 45 km (WLTP) | 12 | 4 | 510 | 1.6 | 70 |

**Table 16 – Nissan and Mitsubishi e-LCV characteristics [49] [50]**

- **Volkswagen**

In addition to its collaboration with Ford, the company with its four sub-brands plans to produce 27-MEB models with the first model of VW I.D. van. Similar to other German manufacturer Mercedes-Benz, VW invested €44billion in order to promote e-mobility and improve new customer services and digitalization while converting their vans into electric such as Transporter, ID Buzz and e-Crafter. As the table shows VW's LCVs range, German company has decided to not offer the electric model of Caddy due to improvement on the MQB platform while e-Crafter is top selling large segment model both presenting short charging time and a satisfactory load capacity in Europe.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| VW e-Caddy (cancelled) | Compact van | 257 km (NEDC) | 37.4-77.6 | N.A. | 636 | 4.2 | 82 |
| VW eTransporter (2020) | Midsize van | 138 km (WLTP) | 32,5 | 5,5 | 990-996 | 4.4 - 6.7 | 83 |
| VW I.D. Buzz Cargo (2022) | Midsize van | 500 km (NEDC) | 111 | N.A. | 800 (estimated) | N.A. | 201 (hp) |
| VW e-Crafter (2020) | Large van | 171 km (NEDC) | 37,3 | 5.30 | 1000-1750 | 10.7 | 100 |

**Table 17 - VW e-LCVs characteristics**

- **Chinese Manufacturers and other e-LCVs in the market**

Light commercial vehicle manufacturers based in China, Maxus, Dongfeng Sokon, SAIC(LDV) are illustrated below with their characteristics of battery electric powertrains. It is clear that new entrant Maxus offers a longer driving range with a favorable charging time depending on battery capacity for different van segments. On the other hand, some European brands have given as an example, like MAN as a part of VW group produced its large segment e-LCV e-TGE in Poland with its identical sister model e-Crafter. [51] Another European manufacturer Goupil offers more than twenty versions of electric vehicles with a variety of body version such as box, caged, fridge or high pressure washer vans in order to be used generally in street cleaning, maintenance or small-medium industrial applications [52]. As it can be seen from the table, they have a wide range of electric vans in different segments.

| LCV Brand | LCV type | Driving Range (Test Cycle) | Battery Capacity (kWh) | Charge Time (hours) | Payload (kg) | Volume (m3) | Max Engine Power (kW) |
|---|---|---|---|---|---|---|---|
| Maxus eDeliver 3 | Compact van | 227-344 km (WLTP) | 35 & 52,5 | 6 | 865 & 905 | 4,8 | 90 |
| Sokon / DFSK EC35 (2020) | Midsize van | 259 km | 42 | N.A. | 900 | 5 | 60 |
| LDV EV80 | Large van | 190 km (NEDC) | 56 | 8,5 | 1100 | 10,4 | 56 |
| Maxus e Deliver 9 (2021) | Large van | 180-235 km (WLTP) | 51.5 & 72 | 6 & 8 | 1200 & 860 | 9.7 & 11 | 70 |
| Morris Commercial JE (2020) | Midsize van | 320 km (untested claim) | 60 | N.A. | 1000 | 5.5 | N.A. |
| MAN e-TGE (2021) | Large van | 110-115 km (WLTP) | 35,8 | 5,3 | 950 | 10,7 | 100 |
| Goupil G2 | Pick-up | 61-100 km (WLTP) | 5,2-8,6 | 6,5 | 478 & 596 | 1,25 | 11,5 |
| Goupil G4 | Small van | 60-75 km (WLTP) | 9 & 14 | 4,25 & 9,75 | 1022 | 3 | 16,3 |
| Goupil G5 | Compact van | 150 km (WLTP) | 11,5 & 19,2 | 5 & 8,3 | 760 | 6 | 21,7 |

**Table 18 - Other manufacturers' e-LCV characteristics**

Lastly, the chart shows an estimation of LCV fleet compositions by 2025 based on the OEMs announcements by Ricardo Energy and Environment [53].

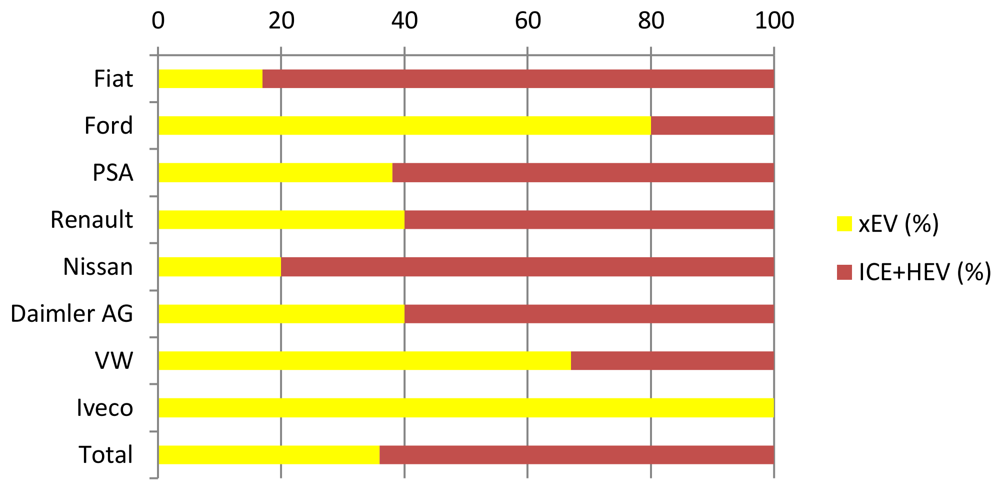



**Figure 18 - 2025 LCV fleet shares estimation for each van manufacturer**

Another report published by the same R&D center indicates the estimated average range of e-LCVs for different segments by taking into account overall costs of battery for the years of 2020, 2025 and 2030. It is obvious that developments on small segment e-LCVs are highly dependent on the battery cost and size/mass improvements so a high increase in driving range is not expected with the aim of reducing overall cost. Nevertheless, other segments are likely to make a huge progress in terms of range/utility with respect to small one in 2020 and beyond. On the other hand, pure electric range of PHEVs and REEVs is considered as remaining unchanged during the overall period [54].

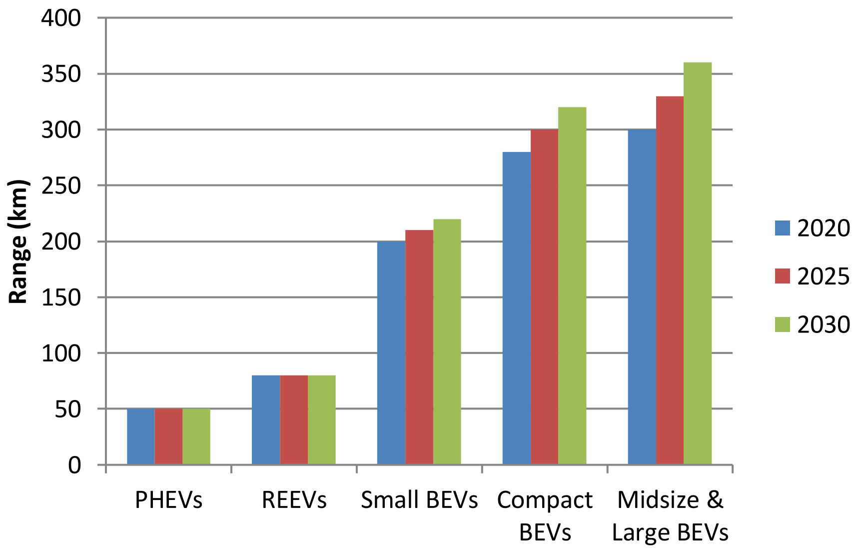



**Figure 19 – Estimations on pure electric range for e-LCVs between 2020 and 2030**

# 4 IMPACT ASSESSMENTS OF LCV CO2 EMISSION REGULATIONS FROM 2020 ONWARDS

The European Parliament and the Council of the European Union has established CO2 emission requirements setting an average of 175 g CO2/km for new LCVs by 2017 with regulation (EU) No 510/2011, however, this target has already reached four year ahead of schedule by most LCV manufacturers. According to the same regulation, the new EU fleet-wide average emission target is set to 147 g CO2/km from 2020 on. Progressively, new CO2 emission targets are defined in the regulation (EU) 2019/631 that apply from 2025 and 2030 as a percentage reduction of 15% and 31% based on 2021 WLTP values, respectively, with new incentives mechanism of ZLEV benchmark and CO2 emission measurement method. Thereby, vans manufacturers envisaged that improving only conventional vehicles to lower the CO2 emissions without investing alternative technologies to meet current emission targets make them pay billion-euro fines in the long run so that almost all LCV manufacturers have decided to switch their sales to electrified vans or stop the sales of ICE-powered vehicles with relative higher emissions. According to study of Transport Environment [24], there are various types of strategies in order to comply with CO2 emission regulations, therefore, to avoid fines that:

- Increasing EV market penetration with low- and zero-emission technologies that produce less/zero CO2 such as BEV, PHEV, REEV and/or FCEV help to tackle climate change and stringent emission standards for the entire fleet.
- Shifting toward hybrid electric vehicles, especially 48 V mild hybrid and full hybrids, and lower emitting models of conventional vehicles with improved engine efficiency and after-treatment systems assists OEMs to meet their targets in the short term.
- Another compliance strategy is to pool with other vehicle manufacturers to achieve reference CO2 targets by combining the emission levels between OEMs or in the same group as explained in the section 3.1 that is allowed by regulations that could preserve from loss.
- Incentive mechanisms of super-credits and/or ZLEV credits could help manufacturers to achieve their goals providing that LCVs emitting less than 50 g CO2/km as well as eco-innovations for emission reduction technologies that do not contribute benefit on test cycles but in real-world.
- Investing the technologies such as downsizing to reduce cylinder displacement, optimized gearbox ratios, thermal management technologies that provide higher CO2 emission reductions based on NEDC with respect to

WLTP may help having a potential high 2021 WLTP fleet-wide target in order to obtain higher fleet WLTP target for 2025 and 2030.

### 4.1 Fleet Composition

In this section, scenario-based analysis over a fleet composition is carried out in order to show the effects of CO2 emission regulations in terms of CO2 emission reduction technologies with alternative powertrains and their additional manufacturing costs through further development of financial modeling. For this reason, LCV fleet composition is determined by selecting 2013 base vehicles for small, compact and large segments defined in the Ricardo study and they are subdivided into classes described in section2.1 according to EU regulation, with specified NEDC emission levels, mass in running orders and market shares for a selected LCV manufacturer by using EEA's 2013 final database [6]. As it can be seen from the graph, the market shares of LCVs in fleet composition have been varying depending on sales numbers in newly registered reference years between the period of 2013 and 2019 that a high proportion of LCVs is composed of class III vans of midsize and large segments. In order to quantify the fleet composition beyond 2020, market distribution is assumed to be 12% for class I and market share of 33% and 55% for class II and class III are expected, respectively, by taking into consideration that demands for load space and payload will remain unchanged for each segment.

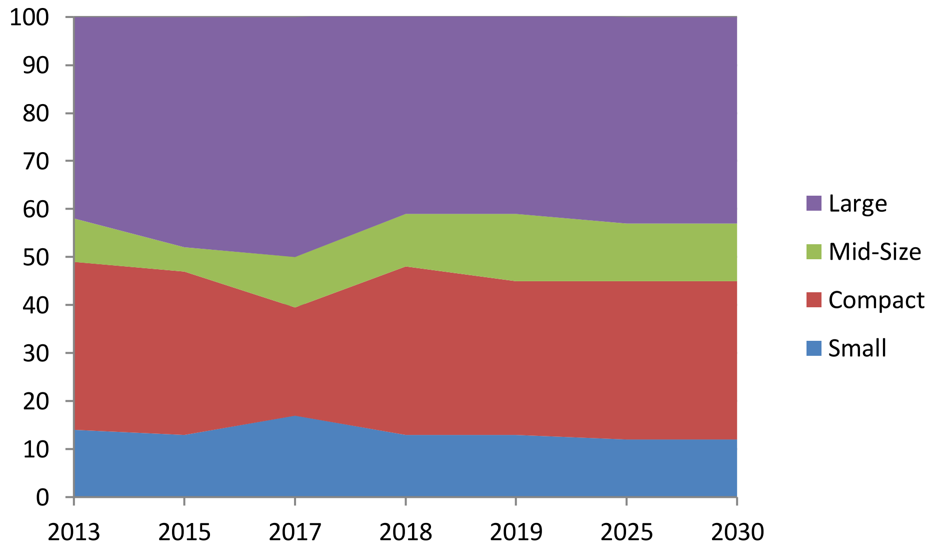



**Figure 20 - Market shares of selected LCV manufacturer between 2013 and 2019**

Afterwards, NEDC CO2 emissions and mass in running orders of selected LCV segments with fuel types of petrol (alternative fuels such as LPG, CNG are included in petrol-powered vans but they are not analyzed in this study because of their small percentages of the total sales) and diesel are determined by monitoring the same report file of EEA's 2013 final database. However, conversion factors are needed to convert emission values from NEDC to WLTP for the reason that CO2 emission measurements are carried out on LCVs based on new standardized driving cycle, WLTC, from 2019 on so that these uplift factors developed by JRC study are used depending on each powertrain type and segment. Thereby, fleet composition is defined as summarized below in terms of NEDC and WLTP emission values, mass in running orders and sales distributions with LCVs based on 2013 datasets. In addition, only large segment LCVs are analyzed in this study by taking into account the similarity of technology and performance characteristics between midsize and large segments.

| Vehicle Class | Fuel Type | Market share (%) | MRO (kg) | NEDC (g/km) | WLTP (g/km) |
|---|---|---|---|---|---|
| Class I | Petrol | 4,00 | 1255,00 | 148,00 | 179,82 |
| | Diesel | 10,00 | 1275,00 | 119,00 | 155,30 |
| Class II | Petrol | 4,00 | 1430,00 | 169,00 | 205,34 |
| | Diesel | 31,00 | 1410,00 | 145,00 | 189,23 |
| Class III | Diesel | 51,00 | 2050,00 | 195,00 | 254,48 |
| | | **Total** | 1717,50 | 168,98 | 219,38 |

**Table 19 - Fleet Composition of LCVs in 2013**

CO2 emission targets based on NEDC values for 2014, 2017 and 2020 are calculated as described in EU regulations by using equations 3.1 and 3.2 in order to show the difference of more ambitious target 2020 with respect to 2017 target of 175 g CO2/km that could be met four years ahead.

| | |
|---|---|
| 2014 Limit | 176,07 |
| 2017 Limit | 170,45 |
| 2020 Limit | 142,31 |

**Table 20 - Mass-based Fleet-wide targets**

By taking into account the strategies explained above that relieve the impacts of CO2 emission levels and help cost cutting in fleet composition, the market shares of petrol-powered LCVs is replaced with diesel one both for class I and class II because of their heavy burden of CO2 emission effects on average fleet emission value and less competitive characteristics such as fuel saving and demanded torque with respect to diesel vans, thus, fleet composition is completed to examine reference CO2 emission targets from 2020 onwards.

### 4.2 2020 CO2 Emission Targets

According to EU regulation, 2020 target value is set as 147 g/km of CO2 based on NEDC so that equation 3.3 as shown below can be used to determine the CO2 emission limits.

Specific emission target= 147 + 0,096 * (M – 1766,4) [g CO2/km]

Also if it is taken into consideration that the fine is €95 per gram of CO2 for 2020 target exceedance and market shares of each van is assumed in thousand units, the potential penalties for each vehicle segment are calculated by assuming that vehicle masses remain unchanged in business as usual case.

| Vehicle Class | Fuel Type | Market share (%) | MRO (kg) | NEDC (g/km) | NEDC Target (g/km) | Penalty (M€) |
|---|---|---|---|---|---|---|
| Class I | Diesel | 12 | 1275,00 | 119,00 | 99,83 | 21,86 |
| Class II | Diesel | 33 | 1410,00 | 145,00 | 112,79 | 100,99 |
| Class III | Diesel | 55 | 2050,00 | 195,00 | 174,23 | 108,55 |

**Table 21 - 2020 NEDC Based Limits and Potential Penalties**

#### 4.2.1 Improvements on CO2 reduction technologies and costs of LCVs

In order to avoid paying huge amounts of fines and protect financial benchmarks in a given year, it is necessary to invest in new technologies for the reduction of tailpipe CO2 emission levels and for advancements on vehicle performance as well. After current state-art powertrain technologies which are able to compete with alternative powertrains up to 2030 are investigated in the first part for conventional LCVs, hybridization options are assessed depending on the CO2 reduction performance for each vehicle segment providing different advancements such as engine, transmission and driving resistance reduction technologies by using Ricardo cost curves [54]. Also, CO2 reduction effects on WLTP should be taken into account in order to have released CO2 targets beyond 2020, as mentioned in the section of emission reduction strategies overall fleet despite the fact that it is important to identify technologies to meet 2020 specific CO2 targets based on NEDC. It should be noted that eco-innovation technologies are not included in technology options for this study.

**Micro-Hybrid**: Brake energy recuperation/regeneration of 12 V alternator that feed the battery and engine start/stop system are included in the micro-hybrid vehicles that contributes significant CO2 reduction both for NEDC and WLTP.

**Mild-Hybrid**: In addition to characteristics of mild-hybrid, an electric motor with 48V operating voltage working parallel with ICE acts as electric turbocharger to supply additional drive torque while allowing recuperation function. Electric motor reaches its maximum torque from zero speed when the vehicle is at low speeds and boosts the drive torque. This technology is much cheaper even though it has a smaller 48 V Lithium-ion battery and less powerful electric motor with respect to full hybrid.

**Aerodynamics improvements**: Improvements in aerodynamic characteristics aid to reduce emission consumption with a reduction in aerodynamic drag by integrating side skirts, underbody skirts, spoiler or diffuser.

**Optimizing gearbox ratios or downspeeding**: Increased number of gears with reduced gear ratios allow to lower the engine friction and to increase the fuel efficiency as well as offering better maneuver dynamics for drivers.

**Downsizing**: Downsizing strategy relies on reducing cylinder displacement with similar or better performance of the engine by matching with a turbocharger system to supply more air into the cylinder with turbine propelled by engine exhaust gases.

**Weight reduction**: Reduction of weight on the entire vehicle, as assumed to be -10%, can be realized by using the light metals such as aluminum, magnesium and advanced steels with increased strength properties.

**Thermal management**: This technology including heat storage systems, integrated exhaust manifolds and cylinder head cooling system contribute fuel saving by capturing thermal energy that can be stored for an hour coming from combustion during warm-up.

The CO2 saving potentials with added technology options are shown below for each segment. As taking into account the sensitivity of included technologies, weight reductions are assumed 8% for micro-hybrid and 7% for mild hybrid type. Mild hybrid powertrain technology is implemented on compact segments with CO2 improvement up to almost 30% on the NEDC, 19% on the WLTC while micro-hybrid with different technologies are considered for base LCVs of other segments.

| Small Van | %CO2/Energy Reduction | | Cost (€) | | |
|---|---|---|---|---|---|
| Technologies | NEDC | WLTP | 2020 | 2025 | 2030 |
| Micro Hybrid | 4,7 | 4,7 | € 316 | € 237 | € 220 |
| Medium Downsizing | 6,6 | 3,2 | € 143 | € 194 | € 194 |
| Aerodynamics Improvement (Cd reduced by 10%) | 2,3 | 3,4 | € 44 | € 40 | € 38 |
| Thermal Management | 2,3 | 1,2 | € 92 | € 75 | € 61 |
| Mild weight reduction (10%) | 5,6 | 4,7 | € 39 | € 36 | € 34 |
| Optimizing gearbox ratios | 3,1 | 2,2 | € 61 | € 49 | € 41 |
| Total | 24,6 | 19,4 | 695,36 € | 631,45 € | 587,65 € |

**Table 22 - Small van segment Technology Packages and Equivalent Costs**

| Compact Van | %CO2/Energy Reduction | | Cost (€) | | |
|---|---|---|---|---|---|
| Technologies | NEDC | WLTP | 2020 | 2025 | 2030 |
| Mild Hybrid | 11 | 4,9 | € 1.129 | € 878 | € 798 |
| Medium Downsizing | 6,4 | 2,8 | € 152 | € 207 | € 207 |
| Aerodynamics Improvement (Cd reduced by 10%) | 2,5 | 3,9 | € 55 | € 51 | € 48 |

| | | | | | |
|---|---|---|---|---|---|
| Thermal Management | 2,2 | 1,1 | € 134 | € 109 | € 88 |
| Mild weight reduction (10%) | 5,1 | 4,6 | € 47 | € 43 | € 41 |
| Optimizing gearbox ratios | 2,6 | 1,8 | € 61 | € 49 | € 41 |
| **Total** | 29,8 | 19,1 | 1.578,73 € | 1.336,93 € | 1.222,94 € |

**Table 23 - Compact van segment Technology Packages and Equivalent Costs**

| **Large van** | **%CO2/Energy Reduction** | | **Cost (€)** | | |
|---|---|---|---|---|---|
| **Technologies** | **NEDC** | **WLTP** | **2020** | **2025** | **2030** |
| **Micro Hybrid** | 4,2 | 3,2 | € 399 | € 300 | € 278 |
| **Mild Downsizing** | 3,4 | 1,5 | € 52 | € 47 | € 47 |
| **Aerodynamics Improvement (Cd reduced by 10%)** | 2,9 | 4,6 | € 66 | € 61 | € 57 |
| **Thermal Management** | 1,9 | 1 | € 193 | € 157 | € 127 |
| **Mild weight reduction (10%)** | 5,7 | 4,4 | € 88 | € 81 | € 77 |
| **Optimizing gearbox ratios** | 2,8 | 2 | € 61 | € 49 | € 41 |
| **Total** | 20,9 | 16,7 | 859,34 € | 694,36 € | 625,82 € |

**Table 24 - Large van segment Technology Packages and Equivalent Costs**

### 4.2.2 Cost-Benefit Analysis

Most van makers have been preparing to comply with existing and future CO2 emission targets by organizing their production activities, supply chain management and sales strategies to improve gross margins of their companies. The assessments on the most cost-effective solution to find a technological advance can be complicated or expensive depending on the benefit of their value-chain strategy on a product. Therefore, the decision of making an investment on specific technologies can be identified with cost-benefit ratio by setting a threshold of 95 €/(g/(km)) from LCV manufacturers' perspective because if any technology mix exceeds this threshold, profitability of the business can fall dramatically depending on the amount of fine defined in EU regulation, even resulting in dead investment. As it can be seen on the graph, cost-benefits ratios are calculated according to relation between total costs of manufacturing and emission reductions based on NEDC and WLTC reflecting overall performance so, expectedly, mild-hybrid technology developed on compact segments has the highest ratio with respect to micro type.

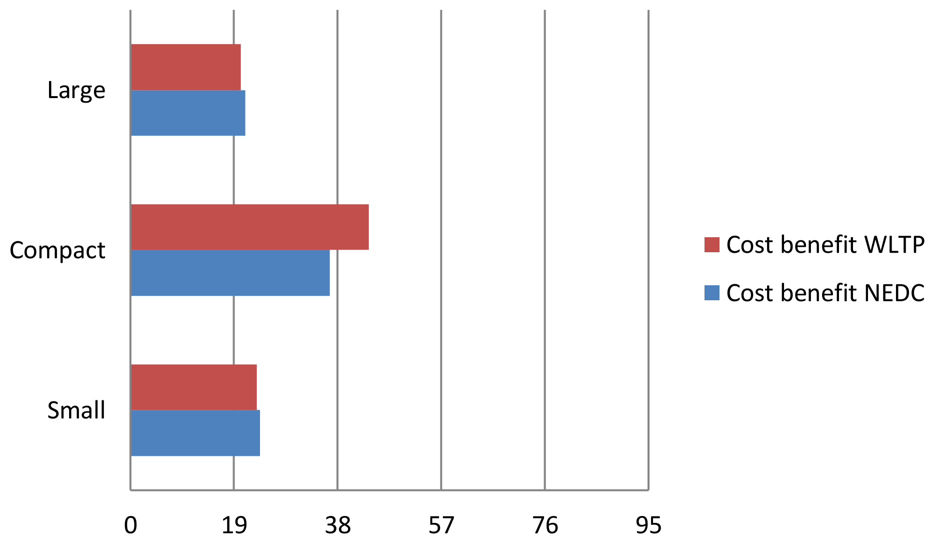



**Figure 21 - Cost/Benefit Analysis**

### 4.2.3 Compliance with specific emission targets in 2020

It is apparent that reduction in vehicle mass causes a more challenging CO2 target in spite of its benefit in terms of CO2 reduction. Nevertheless, all segments achieve their specific targets calculated based on their masses, with CO2 reduction thanks to selected technology options by taking into account 2013 base vehicles, instead of paying any sanctions. The figures illustrate the compliance of specific emission targets with new NEDC and WLTP values.

| Segment | Small | Compact | Large |
|---|---|---|---|
| Year | 2020 | 2020 | 2020 |
| MRO (kg) | 1173 | 1311,30 | 1886 |
| NEDC (gCO2/km) | 89,73 | 101,79 | 154,25 |
| Target NEDC (gCO2/km) | 90,03 | 103,31 | 158,48 |
| WLTP (gCO2/km) | 124,93 | 153,09 | 211,98 |

| Class I (12%) | | | | | | | |
|---|---|---|---|---|---|---|---|
| CI+HEV | | SI REEV | | BEV | | CO2(New) | Limit |
| CO2 | % | CO2 | % | CO2 | % | | |
| 89,73 | 12 | 42,08 | 0 | 0 | 0 | 89,73 | 90,03 |

| Class II (33%) | | | | | | | |
|---|---|---|---|---|---|---|---|
| CI+HEV | | SI PHEV | | BEV | | CO2(New) | Limit |
| CO2 | % | CO2 | % | CO2 | % | | |
| 101,79 | 33 | 58,11 | 0 | 0 | 0 | 101,79 | 103,31 |

| Class III (55%) | | | | | | | |
|---|---|---|---|---|---|---|---|
| CI+HEV | | SI REEV | | BEV | | CO2 (New) | Limit |
| CO2 | % | CO2 | % | CO2 | % | | |
| 154,25 | 55 | 76,33 | 0 | 0 | 0 | 154,25 | 158,48 |

**Table 25 - 2020 Fleet Composition Parameters and Compliance of CO2 limits**

### 4.3 CO2 Emission Targets beyond 2020

Average new LCV CO2 emissions are required to reduce by 15% in 2025and by 31% in 2030 relative to 2020 NEDC and WLTP emission values by taking into account average MRO of newly registered LCVs by all manufacturers and average MRO of LCVs in fleet composition in 2021. These reductions can be expressed as a value of 125 g CO2/km for 2025 and 101 g CO2/km for 2030 based on the current 2020 CO2 target of 147 g/km in NEDC terms. Specific emission targets are defined on the basis of utility parameters which are considered as vehicle mass with a slope of 0,096 that will be used between 2020 and 2024. After this period, the slope will be determined by a least square fit that will be carried out by the EU through CO2 and MROs of all LCVs registered in 2021 for the calculation of fleet-wide specific manufacturer targets of 2025 and 2030 [55] .

### 4.3.1 Powertrain Options

Technology alternatives of LCVs apart from conventional and hybrid vehicles applied in industry as demonstrated in the previous section 3.4.2 are analyzed in terms of CO2 reduction performance and technical characteristics. Electric powertrain options are selected for each LCV segment to be implemented in fleet composition in order to assess their benefits on reduction of CO2 emission for overall fleet according to financial analysis as well as present and future competitiveness in Europe LCV market from different points of views. For this reason, BEV technology for all vans and REEVs for small and large segments are selected to be developed while PHEV powertrain is evaluated only for compact segments considering that small and compact segments are similar with the aim of examining the effect of different electrified configurations. It is noteworthy that every PHEV and REEV powertrain is combined with SI engine with the aim of reducing dieselization rate and take advantage of downsizing solutions with turbocharging in REEV and larger engine size petrol engine supported with cycles like Atkinson to find best trade-off between power and fuel economy in PHEV powertrain types.

Therefore, in order to assess the costs associated to CO2 reduction on reference targets, selected electrified vans are developed based on the Ricardo study for 2021 e-LCVs and JRC Dione cost curves with different cost types (low, typical and high) representing possible limitations or advancements on electric vehicle technologies over 2025 and 2030 [56]. Optimal CO2 and/or energy consumption reduction is obtained per segment and powertrain by imposing cost-benefit with additional costs resulting from reduction of CO2/energy as indicated below.

| Segment | Cost Type | PWT | Cost (€) | CO2 (g/km) |
|---|---|---|---|---|
| Small | Low | SI REEV | 5500 | 21,5 |
| | | BEV | 3500 | 41,3 |
| | Typical | SI REEV | 6900 | 21,5 |
| | | BEV | 4500 | 42,7 |
| | High | SI REEV | 8500 | 23 |
| | | BEV | 5500 | 43 |
| Compact | Low | SI PHEV | 5000 | 32,5 |
| | | BEV | 5600 | 50 |
| | Typical | SI PHEV | 5900 | 32 |
| | | BEV | 7200 | 51 |
| | High | SI PHEV | 7415 | 33,5 |
| | | BEV | 9950 | 51 |
| Large | Low | SI REEV | 9110 | 20,8 |
| | | BEV | 9050 | 64 |
| | Typical | SI REEV | 10900 | 22 |
| | | BEV | 11550 | 61,5 |
| | High | SI REEV | 14000 | 21,8 |
| | | BEV | 16000 | 61,5 |

| Segment | Cost Type | PWT | Cost (€) | CO2 (g/km) |
|---|---|---|---|---|
| Small | Low | SI REEV | 4680 | 21,3 |
| | | BEV | 2600 | 40 |
| | Typical | SI REEV | 5800 | 23,5 |
| | | BEV | 3640 | 39,7 |
| | High | SI REEV | 7450 | 22,4 |
| | | BEV | 5160 | 40 |
| Compact | Low | SI PHEV | 4120 | 32,8 |
| | | BEV | 4500 | 46 |
| | Typical | SI PHEV | 5120 | 33,5 |
| | | BEV | 6710 | 47 |
| | High | SI PHEV | 6090 | 34,5 |
| | | BEV | 9470 | 47 |
| Large | Low | SI REEV | 7400 | 22 |
| | | BEV | 7520 | 61 |
| | Typical | SI REEV | 9635 | 22 |
| | | BEV | 11100 | 60,5 |
| | High | SI REEV | 12413 | 22 |
| | | BEV | 15310 | 58,8 |

**Table 26 - e-LCVs CO2 emissions/Energy consumptions and equivalent costs for 2025 and 2030**

### 4.3.2 Compliance with WLTP based emission targets from 2021 onwards

CO2 emissions targets are determined based on NEDC test procedure for the newly registered LCVs in 2020. In the meantime, the WLTP based emission values are determined for all new vans in the fleet composition but, as it is expected, transitions from the NEDC into WLTP are not evenly distributed between LCV segments due to variable effect of technology options changing with cycle types.

According to Regulation (EU) 2020/1590, average mass in running order of LCVs registered by manufacturers in the calendar years 2016, 2017 and 2018 was 1825,23 kg, the M0 value for the calendar years 2021, 2022 and 2023 reflects that mass. However, as the average of the mass in running order of all LCVs for 2021 will be known in 2022 and MRO will be replaced with TM0 in 2025 that will be determined based on the average test mass of newly registered LCVs in 2021, it is impossible to provide a quantitative estimation over every reference target years from 2025 onwards. Therefore, if it is assumed that TM0 values both for 2025 and 2030 are the same as estimated 2021 reference average mass, specific emission reference limits of those target years can be interpreted for each segment. As it can be seen from the graph, new 2025 and 2030 target limits can be achieved with two different slope approaches that determine CO2 emissions of LCVs based on lower/higher than average mass in running order.

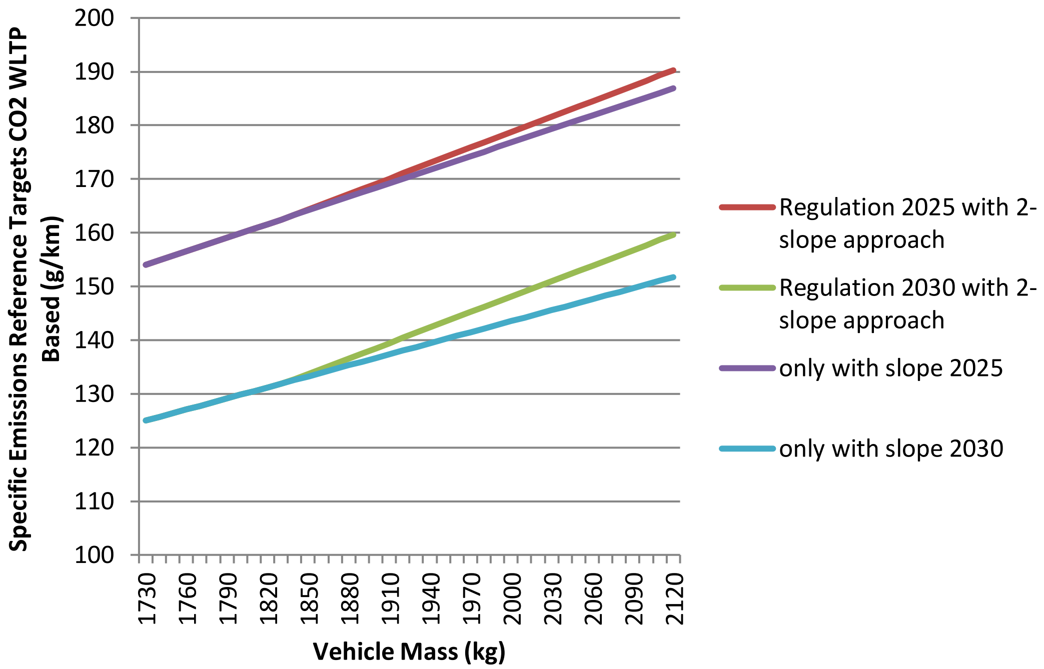



**Table 27 - Specific Emission Reference Targets 2025 and 2030**

Also, mass corrections for extra mass added by electric powertrain options based on increase in market shares of e-LCVs are adapted from Ricardo study shown below. In addition, as batteries weight have a significant impact on kerb weight of LCVs, vans whose weights are adjusted based on the mass correction are assumed to remain in the same class even if they exceed the maximum reference mass depending on regulation about N1 definition threshold. Thus, mass corrections for each alternative powertrain type are shown below;

| Mass Correction | PWT | SI REEV (+) | SI PHEV (+) | BEV (+) |
|---|---|---|---|---|
| | **Mass +/-** | 8% | 3% | 12% |

**Table 28 - Mass Corrections for e-LCVs**

In this point, it is considered to set four annual reduction rates in relation to the 2020 target (in relative terms), by taking into reference EU Commission working document of Impact Assessment, that show the range of ambition in terms of CO2 reduction varying depending on the selected scenario evolutions as illustrated in the table [57].

| Average Annual Reduction Rate | WLTP in 2025 (g/km) | WLTP in 2030 (g/km) |
|---|---|---|
| **2,5%** | 157,67 | 136,53 |
| **3,0%** | 152,37 | 127,53 |
| **3,5%** | 146,52 | 117,90 |
| **4,0%** | 141,31 | 109,69 |

**Table 29 - CO2 Emission Targets for 2025 and 2030 with average annual reduction rates**

First average annual reduction rate of 2,5% is aligned with CO2 emission regulations by taking into account limit curve line associated with specific emissions reference targets in 2025 and 2030. Then, other reduction rates are implemented on fleet distribution by taking into account the advancement in the e-LCV market and more severe CO2 emission targets beyond 2030. According to selected average annual reduction rates, CO2 emission target levels from 2021 to 2030 are shown below.

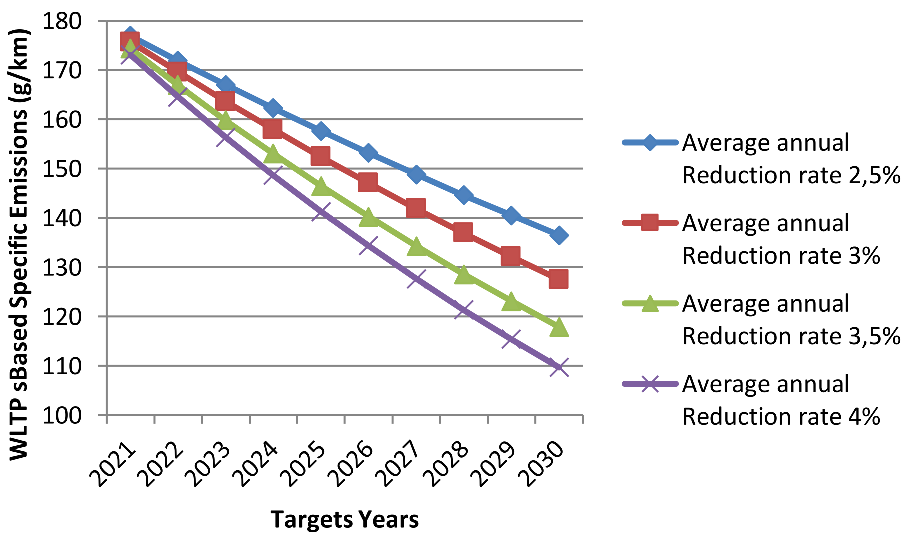



**Figure 22- CO2 reduction target levels between 2021 and 2030**

### 4.3.3 Fleet Composition Scenarios

Scenarios varying with different LCV segments and powertrain types are analyzed depending on different cost developments with regard to powertrain sales distribution overall fleet as long as achieving the compliance with CO2 emission limits based on reduction rates by 2030 which are determined by taking into account the variability in market characteristics in terms of average mass of LCV manufacturers and significant market growth in electrification of LCVs after 2020.

In this way, typical cost types for each powertrain are considered for "Hybrid Scenario" that is most likely scenario considering the current LCV market shares with different combinations that retain pure electric vans majority both in 2025 and 2030. On the other hand, extreme policy variants, namely PHEV/REEV and BEV scenarios with indicated number with respect to target years of 2025 and 2030, are evaluated with low cost types for electric powertrain which sales volume showing relatively strong growth since some vans makers have chosen to focus on particular powertrain developments referring to manufacturers announcements showed in the previous section 3.4.2. Lastly, further cost reduction of battery packs allows to accelerate EV market penetration so that without changing market share obtained in Hybrid Scenario, two different technology scenarios are assessed; one Advance Scenario is simulated to comprehend gaining momentum of e-LCVs with low cost types while Recessive Scenario is executed by high battery cost of low- and zero-emission vans, with an eye to insufficient EV infrastructure, decrease in consumer demand or limited battery supplies.

Thus, fleet distributions of all policy scenarios are illustrated below by taking into consideration 2025 and 2030 CO2 emission limit targets with four different reduction rates that show a level of ambition to decrease emission limits depending on the EV penetration in the LCV market.

In the first case of complying with 2025 CO2 emission targets with 2,5% annual reduction rate, thermal traction systems with hybridized powertrain constitute a vast majority of fleet composition with about 86% in 2025 while stringent emission targets force manufacturers to sell more e-LCVs within 5 years. Clearly, both registration numbers of PHEV/REEVs and BEVs almost double their market shares. On the other hand, more ambitious CO2 reduction levels highly affect the capacity of alternative powertrains within the fleet composition. As it can be seen from the figure, about one quarter of the fleet is composed of e-LCVs in 2030.

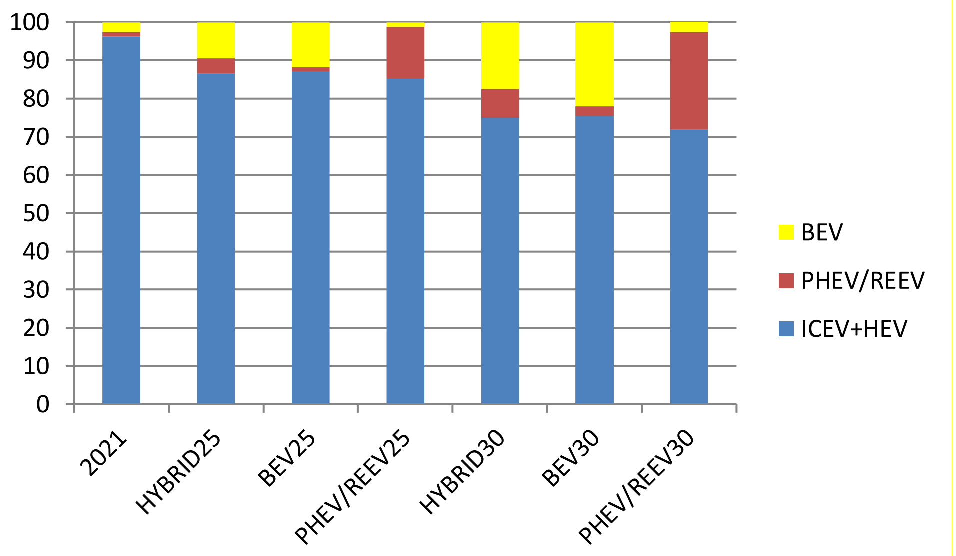



**Figure 23 - Fleet Composition Scenarios between 2021 and 2030 (2,5% annual reduction rate)**

| Target Year | 2025 | 2025 | 2025 | 2025 | 2025 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID25 | BEV25 | PHEV/REEV25 | ADVANCE25 | RECESSIVE25 |
| **ICEV+HEV** | Typical (86,5%) | Typical (87%) | Typical (85,25%) | Typical (86,5%) | Typical (86,5%) |
| **PHEV/REEV** | Typical (4%) | Typical (1,25%) | Low (13,5%) | Low (4%) | High (4%) |
| **BEV** | Typical (9,5%) | Low (11,75%) | Typical (1,25%) | Low (9,5%) | High (9,5%) |

**Table 30 - Fleet Composition Scenarios in 2025 (2,5% annual reduction rate)**

| Target Year | 2030 | 2030 | 2030 | 2030 | 2030 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID30 | BEV30 | PHEV/REEV30 | ADVANCE30 | RECESSIVE30 |
| **ICEV+HEV** | Typical (75%) | Typical (75,5%) | Typical (72%) | Typical (75%) | Typical (75%) |
| **PHEV/REEV** | Typical (7,5%) | Typical (2,5%) | Low (25,5%) | Low (7,5%) | High (7,5%) |
| **BEV** | Typical (17,5%) | Low (22%) | Typical (4,75%) | Low (17,5%) | High (17,5%) |

**Table 31 - Fleet Composition Scenarios in 2030 (2,5% annual reduction rate)**

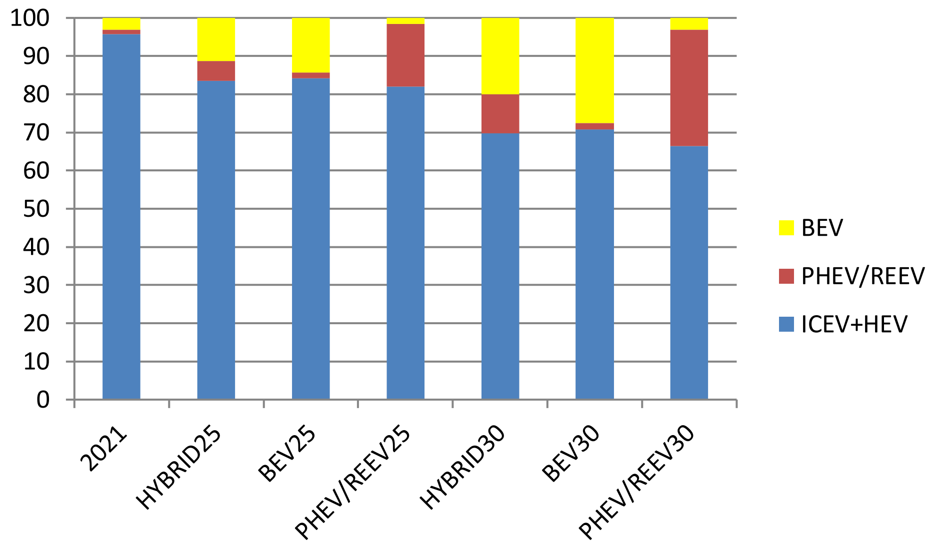



**Figure 24 - Fleet Composition Scenarios between 2021 and 2030 (3% annual reduction rate)**

| Target Year | 2025 | 2025 | 2025 | 2025 | 2025 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID25 | BEV25 | PHEV/REEV25 | ADVANCE25 | RECESSIVE25 |
| **ICEV+HEV** | Typical (83,5%) | Typical (84,25%) | Typical (82%) | Typical (83,5%) | Typical (83,5%) |
| **PHEV/REEV** | Typical (5,25%) | Typical (1,5%) | Low (16,5%) | Low (5,25%) | High (5,25%) |
| **BEV** | Typical (11,25%) | Low (14,25%) | Typical (1,5%) | Low (11,25%) | High (11,25%) |

**Table 32 - Fleet Composition Scenarios in 2025 (3% annual reduction rate)**

| Target Year | 2030 | 2030 | 2030 | 2030 | 2030 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID30 | BEV30 | PHEV/REEV30 | ADVANCE30 | RECESSIVE30 |
| **ICEV+HEV** | Typical (69,75%) | Typical (70,75%) | Typical (66,5%) | Typical (69,75%) | Typical (69,75%) |
| **PHEV/REEV** | Typical (10,25%) | Typical (1,75%) | Low (30,5%) | Low (10,25%) | High (10,25%) |
| **BEV** | Typical (20%) | Low (27,5%) | Typical (3%) | Low (20%) | High (20%) |

**Table 33- Fleet Composition Scenarios in 2030 (3% annual reduction rate)**

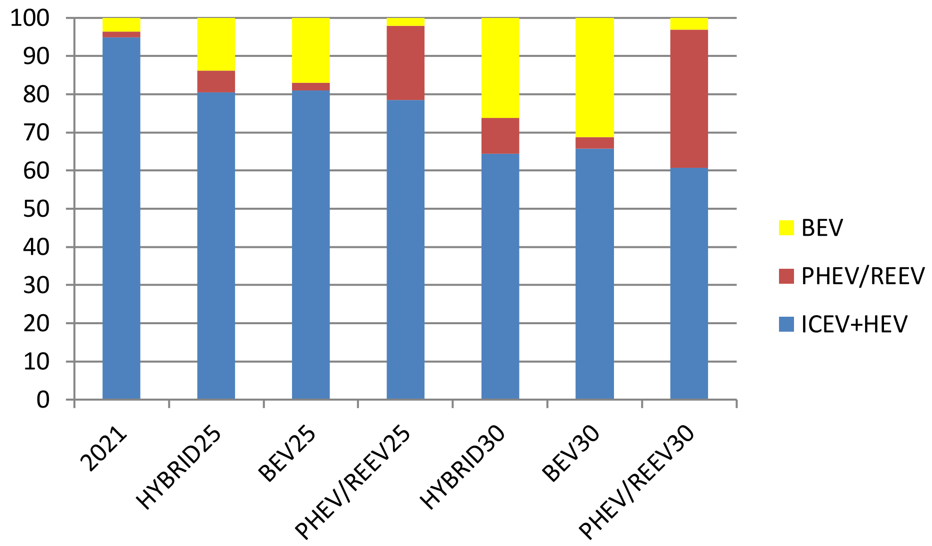



**Figure 25 - Fleet Composition Scenarios between 2021 and 2030 (3,5% annual reduction rate)**

| Target Year | 2025 | 2025 | 2025 | 2025 | 2025 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID25 | BEV25 | PHEV/REEV25 | ADVANCE25 | RECESSIVE25 |
| **ICEV+HEV** | Typical (80,5%) | Typical (81%) | Typical (78,5%) | Typical (80,5%) | Typical (80,5%) |
| **PHEV/REEV** | Typical (5,75%) | Typical (2%) | Low (19,5%) | Low (5,75%) | High (5,75%) |
| **BEV** | Typical (13,75%) | Low (17%) | Typical (2%) | Low (13,75%) | High (13,75%) |

**Table 34 - Fleet Composition Scenarios in 2025 (3,5% annual reduction rate)**

| Target Year | 2030 | 2030 | 2030 | 2030 | 2030 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID30 | BEV30 | PHEV/REEV30 | ADVANCE30 | RECESSIVE30 |
| **ICEV+HEV** | Typical (64,5%) | Typical (65,75%) | Typical (60,75%) | Typical (64,5%) | Typical (64,5%) |
| **PHEV/REEV** | Typical (9,25%) | Typical (3%) | Low (36,25%) | Low (9,25%) | High (9,25%) |
| **BEV** | Typical (26,25%) | Low (31,25%) | Typical (3%) | Low (26,25%) | High (26,25%) |

**Table 35 - Fleet Composition Scenarios in 2030 (3,5% annual reduction rate)**

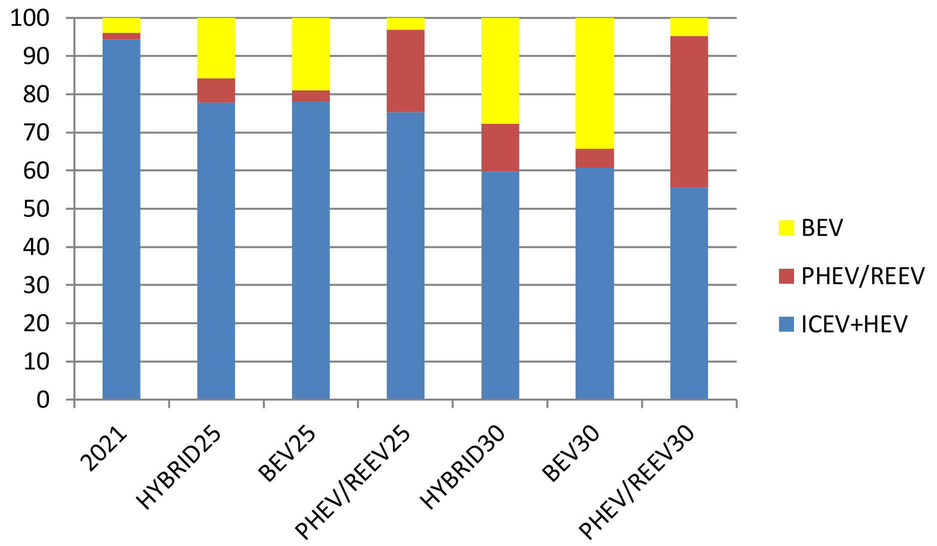



**Figure 26 - Fleet Composition Scenarios between 2021 and 2030 (4% annual reduction rate)**

| Target Year | 2025 | 2025 | 2025 | 2025 | 2025 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID25 | BEV25 | PHEV/REEV25 | ADVANCE25 | RECESSIVE25 |
| **ICEV+HEV** | Typical (77,75%) | Typical (78%) | Typical (75,25%) | Typical (77,75%) | Typical (77,75%) |
| **PHEV/REEV** | Typical (6,5%) | Typical (3%) | Low (21,75%) | Low (6,5%) | High (6,5%) |
| **BEV** | Typical (15,75%) | Low (19%) | Typical (3%) | Low (15,75%) | High (15,75%) |

**Table 36 - Fleet Composition Scenarios in 2025 (4% annual reduction rate)**

| Target Year | 2030 | 2030 | 2030 | 2030 | 2030 |
|---|---|---|---|---|---|
| **Scenario** | HYBRID30 | BEV30 | PHEV/REEV30 | ADVANCE30 | RECESSIVE30 |
| **ICEV+HEV** | Typical (59,75%) | Typical (60,75%) | Typical (55,5%) | Typical (59,75%) | Typical (59,75%) |
| **PHEV/REEV** | Typical (12,5%) | Typical (5%) | Low (39,75%) | Low (12,5%) | High (12,5%) |
| **BEV** | Typical (27,75%) | Low (34,25%) | Typical (4,75%) | Low (27,75%) | High (27,75%) |

**Table 37 - Fleet Composition Scenarios in 2030 (4% annual reduction rate)**

### 4.4 Financial Modeling

In order to evaluate the company's ability to make a profit, it is a better way to determine net profit for every product by taking into account sales revenue and expenses such as penalties, losses and other operational costs. Nowadays, van manufacturers try to find a profitable way to comply with EU CO2 emission regulations that impose a penalty €95 per gram per vehicle exceeding emission limit by following different strategies in the short and longer terms. As an example, Renault is to introduce only pure electric vans for all segments while LEVC offers REEV compact vans similar to midsize vans of Ford Transit Custom. For this reason, investors in the LCV market look forward to how to survive in the game with economic growth by searching best-fit powertrain alternatives as well as avoiding fines. However, according to a report by McKinsey consulting group, today most automakers do not profit from the sales of electric vehicles because of high production and battery costs but the study indicates that electric vehicles will reach profitability close to cost parity of conventional vehicles with the improvements of battery costs and effectiveness by 2025 [58]. In the light of this information, it is essential to implement a financial analysis on profitability per vans positioned in the market for sale as created in the policy scenarios by taking into consideration different products could be more profitable than others or either they can cause losses depending on the production costs, technology investments and marketing strategy. Therefore, in this study, revenue per small segment van is determined as €2000 while compact and large segments have €2500 and €3000 of revenue, respectively. On other hand, gross profits or losses for alternative powertrains are calculated based on battery costs as following: 7% of gross profit for PHEV/REEV sales and 10% losses over cost of battery packs for BEVs in 2021. These net profit ratios increase by 10% in 2025 and 20% in 2030 for PHEV/REEVs while BEVs are designed to be profitable by a ratio 5% over battery cost in 2025 and by 15% in 2030 per vans sold. In addition to cost impact assessment on profitability from the point of view of business, the average technology costs per LCV sold emerging from equivalent scenarios are compared to evaluate the consumers afford to buy alternative powertrains with higher price.

It can be seen from the tables that there are four different scenarios demonstrating financial analysis of the period between 2020 and 2021 (in case M0 value is 1833,67 kg in 2021) with two policy variants. In the 2020 scenario, LCVs included in the fleet are developed to meet specific emission targets so gross profits are calculated per segment by taking into account revenue and technology costs and it is multiplied with sales figure while 2020 BAU scenario follows strategy without investing new technologies in LCVs and consent given fine according to regulation. On the other side, two different figures shown in the table one represents “do nothing” strategy in other words following business as usual and second depends on introduction of electric powertrains in order to meet required legislations regarding CO2 limits. It is obvious that better consequences can be obtained in terms of profitability with showing a tendency to advancements on LCVs both for hybrid and alternative powertrains from 2020 onwards instead of paying fines even though BEV sales do not make money in 2021. Another positive aspect is that part of saving can be liquidated in investments to produce new technology options in reference target years; also, it contributes to company’s ability to achieve success in business in the long-term.

| Target Year | 2020 | 2020 | 2021 | 2021 |
|---|---|---|---|---|
| **Scenario** | 2020 BAU | 2020 | 2021 BAU | 2021 |
| **ICEV+HEV** | Typical (100%) | Typical (100%) | Typical (100%) | Typical (96,75%) |
| **PHEV/REEV** | Typical (0%) | Typical (0%) | Typical (0%) | Typical (1%) |
| **BEV** | Typical (0%) | Typical (0%) | Typical (0%) | Typical (2,25%) |

**Table 38 - Fleet Composition Scenarios in 2020 and 2021**

| Segment | PWT | Gross Profit/Loss per vehicle (€) | Revenue (M€) | Penalty (M€) | Net Profit (M€) |
|---|---|---|---|---|---|
| **Small** | CI HEV | 2000 | 24000 | 21853,80 | 2,15 |
| | SI REEV | 483 | 0 | 0,00 | 0,00 |
| | BEV | 225 | 0 | 0,00 | 0,00 |
| **Compact** | CI HEV | 2500 | 82500 | 100978,35 | -18,48 |
| | SI PHEV | 413 | 0 | 0,00 | 0,00 |
| | BEV | 360 | 0 | 0,00 | 0,00 |
| **Large** | CI HEV | 3000 | 165000 | 108523,25 | 56,48 |
| | SI REEV | 763 | 0 | 0,00 | 0,00 |
| | BEV | 577,5 | 0 | 0,00 | 0,00 |
| | | | | Total | 40,14 |

**Table 39 - Financial Analysis Results of 2020 BAU Scenario**

| Segment | PWT | Gross Profit/Loss (€) | Net Income (M€) |
|---|---|---|---|
| Small | CI HEV | 1304,64 | 15,66 |
| | SI REEV | 483 | 0,00 |
| | BEV | 225 | 0,00 |
| Compact | CI HEV | 921,27 | 30,40 |
| | SI PHEV | 413 | 0,00 |
| | BEV | 360 | 0,00 |
| Large | CI HEV | 2140,66 | 117,74 |
| | SI REEV | 763 | 0 |
| | BEV | 577,5 | 0 |
| | | Total | 163,79 |

**Table 40 - Financial Analysis Results of 2020 Scenario**

| Segment | PWT | Gross Profit/Loss | Revenue | Penalty | Net Profit (M€) |
|---|---|---|---|---|---|
| Small | CI HEV | 1304,64 | 15655,68 | 6874,20 | 8,78 |
| | SI REEV | 483 | 0 | 0,00 | 0,00 |
| | BEV | 225 | 0 | 0,00 | 0,00 |
| Compact | CI HEV | 921,27 | 30401,91 | 13167 | 17,23 |
| | SI PHEV | 413 | 0 | 0,00 | 0,00 |
| | BEV | 360 | 0 | 0,00 | 0,00 |
| Large | CI HEV | 2140,66 | 117736,3 | 3291,75 | 114,44 |
| | SI REEV | 763 | 0 | 0,00 | 0,00 |
| | BEV | 577,5 | 0 | 0,00 | 0,00 |
| | | | | Total | 140,46 |

**Table 41 - Financial Analysis Results of 2021 BAU Scenario**

| Segment | PWT | Gross Profit/Loss (€) | Net Income (M€) |
|---|---|---|---|
| Small | CI HEV | 1304,64 | 14,68 |
| | SI REEV | 483 | 0,12 |
| | BEV | -450 | -0,23 |
| Compact | CI HEV | 921,27 | 29,02 |
| | SI PHEV | 413 | 0,21 |
| | BEV | -720 | -0,72 |
| Large | CI HEV | 2140,66 | 115,60 |

| | | | |
|---|---|---|---|
| | SI REEV | 763 | 0,19 |
| | BEV | -1155 | -0,87 |
| | | Total | 158,00 |

**Table 42 - Financial Analysis Results of 2021 Scenario**

Other results shown in the table are determined under different policy and technology scenarios depending on technology advancements in e-LCVs target years of 2025 and 2030 for e-LCVs by comparing the average technology costs increased per van. Apparently, in all cases, customers have to spend much more in order to buy a new LCV to save the world as average retail price increases more than € 1410 (with added mark-up factor) in 2021 with stricter emission target level. Allied to EV market penetration, average price per vehicle in the fleet has an increasing trend over the period 2030 and it is normal that the lowest benefits are obtained in RECESSIVE Scenario which is improved with a high cost approach by taking into account barriers to technology adoption including unexpected increase in battery costs. On the other side, cost effectiveness of policy variants is fluctuating dependent on CO2 emission regulations between 2025 and 2030. Extreme scenarios of PHEV/REEV assuming a dramatic production cost decrease give more average benefit thanks to its higher profit margin with respect to BEV.

Moreover, it is obvious that higher passion in emission reduction accompanied with strong EV penetration overall fleet diminishes profit margin obtained from hybrid vans and causes average vehicle price raise as well. However, profitability is improved with increasing sales of e-LCVs as total vehicle cost is reduced by taking into consideration policy scenarios including low cost types such as BEV, PHEV/REEV and ADVANCIVE, additionally, there are no huge differences in terms of net profits between them in 2030. On the other hand, net profits are likely to drop for HYBRID and RECESSIVE scenarios modeled by typical and high cost types of e-LCVs, respectively.

In addition, due to super-credits not continuing after 2020 for LCVs, another incentive mechanism for zero- and low- emission vehicles (ZLEV) which is introduced from 2025 on is taken into account in fleet compositions. According to EU regulation, 15% ZLEV from 2025 on and 30% ZLEV from 2030 on allow to increase one percent of manufacturers' targets on condition that exceedance of ZLEV benchmark by one percent and so on. Therefore, it can be seen that policy scenarios-except PHEV/REEV versions for annual reduction rates of 3,5% and 4% enable to ease emission targets by overachieving the benchmark both for 2025 and 2030 as shown in the table. Especially, BEV scenarios having high market share of

ZEVs allow for relaxing the challenging regulatory target up to 5% more than other scenarios. However, other options of 2,5% and 3% average annual reduction rates are not able to reduce CO2 reduction targets due to EV shares that are lower than minimum ZLEV sales target.

| Scenario | Net Profit/Loss (M€) | Increase in Tech. Cost per vehicle(€) | ZLEV Factor (%) |
|---|---|---|---|
| **2020 BAU** | 40,14 | 0 | - |
| **2020** | 163,79 | 1077,06 | - |
| **2021 BAU** | 114,67 | 1077,06 | - |
| **2021** | 156,23 | 1541,12 | - |
| **HYBRID25** | 165,12 | 1996,45 | 11,45 |
| **BEV25** | 166,73 | 1737,77 | 12,40 |
| **PHEV REEV25** | 170,63 | 1852,42 | 7,88 |
| **ADVANCE25** | 167,69 | 1748,40 | 11,45 |
| **RECESSIVE25** | 163,60 | 2417,80 | 11,45 |
| **HYBRID30** | 176,71 | 2697,99 | 21,21 |
| **BEV30** | 186,94 | 2112,37 | 23,25 |
| **PHEV REEV30** | 189,37 | 2308,43 | 15,02 |
| **ADVANCE30** | 188,59 | 2085,38 | 21,21 |
| **RECESSIVE30** | 166,87 | 3438,81 | 21,21 |

**Table 43 - Financial Analysis Scenario Results (average annual reduction rate 2,5%)**

| Scenario | Net Profit/Loss (M€) | Increase in Tech. Cost per vehicle(€) | ZLEV Factor (%) |
|---|---|---|---|
| **2021** | 154,71 | 1605,67 | - |
| **HYBRID25** | 161,34 | 2257,47 | 13,85 |
| **BEV25** | 163,18 | 1938,01 | 15,04 |
| **PHEV REEV25** | 168,06 | 2075,65 | 9,61 |
| **ADVANCE25** | 164,57 | 1953,77 | 13,85 |
| **RECESSIVE25** | 159,44 | 2774,36 | 13,85 |
| **HYBRID30** | 174,22 | 3125,68 | 25,15 |
| **BEV30** | 186,85 | 2358,12 | 28,38 |
| **PHEV REEV30** | 189,29 | 2627,97 | 18,02 |
| **ADVANCE30** | 189,20 | 2348,57 | 24,12 |
| **RECESSIVE30** | 162,21 | 4022,59 | 25,15 |

**Table 44 - Financial Analysis Scenario Results (average annual reduction rate 3%)**

| Scenario | Net Profit/Loss (M€) | Increase in Tech. Cost per vehicle(€) | ZLEV Factor (%) |
|---|---|---|---|
| **2021** | 153,04 | 1710,96 | - |
| **HYBRID25** | 157,18 | 2523,37 | 16,58 |
| **BEV25** | 159,27 | 2156,44 | 17,97 |
| **PHEV REEV25** | 165,25 | 2327,84 | 11,75 |
| **ADVANCE25** | 160,99 | 2158,69 | 16,58 |
| **RECESSIVE25** | 154,95 | 3145,92 | 16,58 |
| **HYBRID30** | 170,81 | 3578,34 | 30,84 |
| **BEV30** | 186,13 | 2668,14 | 32,78 |
| **PHEV REEV30** | 189,65 | 2945,95 | 20,95 |
| **ADVANCE30** | 188,21 | 2668,64 | 30,84 |
| **RECESSIVE30** | 156,39 | 4675,39 | 30,84 |

**Table 45 - Financial Analysis Scenario Results (average annual reduction rate 3,5%)**

| Scenario | Net Profit/Loss (M€) | Increase in Tech Cost per vehicle(€) | ZLEV Factor (%) |
|---|---|---|---|
| **2021** | 151,79 | 1792,73 | - |
| **HYBRID25** | 153,49 | 2776,23 | 19,05 |
| **BEV25** | 155,78 | 2381,22 | 20,53 |
| **PHEV REEV25** | 162,07 | 2569,37 | 13,81 |
| **ADVANCE25** | 157,91 | 2356,41 | 19,05 |
| **RECESSIVE25** | 150,90 | 3493,62 | 19,05 |
| **HYBRID30** | 168,62 | 3949,74 | 34,07 |
| **BEV30** | 185,02 | 2961,56 | 36,70 |
| **PHEV REEV30** | 188,97 | 3286,49 | 24,51 |
| **ADVANCE30** | 188,33 | 2935,86 | 34,07 |
| **RECESSIVE30** | 152,31 | 5174,39 | 34,07 |

**Table 46 - Financial Analysis Scenario Results (average annual reduction rate 4%)**

# 5 TOTAL COST OF OWNERSHIP

The analysis of total cost of ownership including all costs associated with usage of vehicle in a limited lifetime is used to assess the competitiveness of different powertrain types of LCVs. Unlike passenger vehicles, LCVs are mostly operated by companies so that investing in a specific technology option with higher retail price should be offset by fuel cost savings and operational cost advantages in the future. Also, in contrast to private customers in the passenger car market, commercial customers base upon their decisions on fuel economy of powertrain type and technical parameters of LCV. For this reason, in order to attract the customers or company fleet operators, it is essential to demonstrate that acquired LCV with alternative powertrain offers an amortization during the ownership period. Total cost of ownership analysis as a version of customer perspective, in this point, plays an important role to convince them total cost of base vehicle, fuel and energy consumption, insurance and maintenance costs and different type of taxes including additional expenses such as LEZ charges and parking fees for LCVs with different powertrain types may show a positive difference with accumulated savings over a total lifetime of vehicle by comparing each other. Therefore, TCO analysis is carried out to determine the suitability of the various powertrains in all segments by using several mathematical parameters explained below for end-users.

## 5.1 Parameters used for TCO Analysis

In this section, methodology used for TCO analysis calculations is explained with key assumptions that are accounted for the following components:

### 5.1.1 Depreciation

Van depreciation that represents the difference between the amounts how much an LCV is worth when it is bought and when it is sold is one of the most important considerations of the total cost of ownership. There are several factors that affect the depreciation rate depending on mileage, fuel effectiveness, brand reputation, damage conditions and powertrain types. The figure depicts annual depreciation rates that are taken from Ricardo study for the assumption in TCO analysis as a remaining value in decreasing percentage on purchase price, that are applied uniformly for all powertrain types and segments by taking into consideration e-LCV market reach its maturity by 2025 even though e-LCVs has higher depreciation today [53].

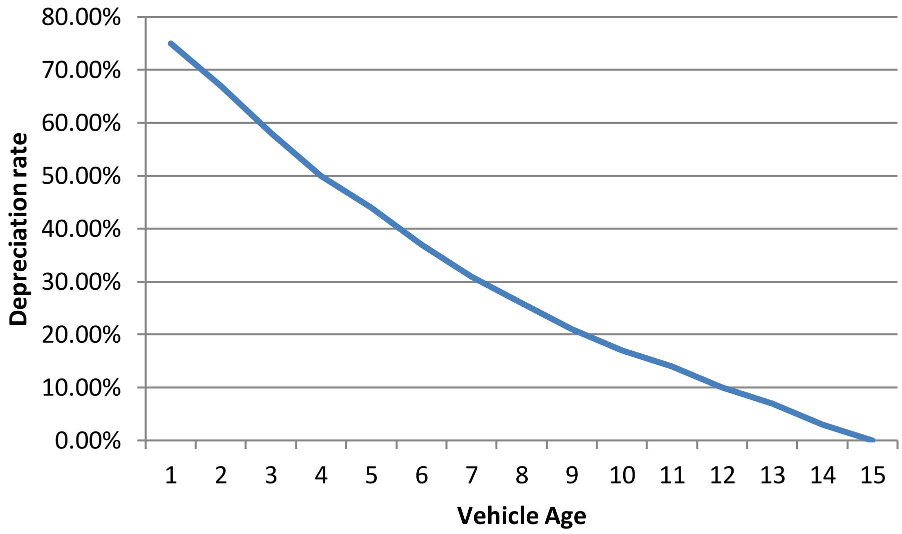



**Figure 27 - Depreciation profile**

### 5.1.2 Base vehicle costs

Base vehicle prices are determined for each powertrain type and segment based on selected vans sold in 2013. As the cost curves of SI REEVs and SI PHEVs are developed by taking into account base petrol-powered conventional vans, it is assumed that they have equal base vehicle cost. TCO analysis is carried out without base vehicle cost difference between diesel LCV and BEV, applying the same parameters related to depreciation.

| PWT / Segment | Small | Compact | Large |
|---|---|---|---|
| **CI** | 11.950 € | 14.900 € | 25.300 € |
| **SI** | 9.940 € | 12.900 € | 23.000 € |

**Table 47 - Base Vehicle Costs**

### 5.1.3 Technology Costs

Optimal technology costs determined with typical cost curves for all e-powertrains and segments in the fleet composition (see table 26) are depreciated by accumulating base vehicle costs according to the depreciation rate described above for each life year of LCV.

### 5.1.4 Mark-up factor

In order to convert technology costs into retail prices including marketing and transportation costs, a mark-up factor of 1.11 taken from Ricardo study is used in the TCO analysis [53].

### 5.1.5 Mileages

Lifetime mileage improvements for all powertrain types and segments are obtained by taking into account an annual reduction rate that shows a sharp drop after the fourth year related to LCV activity analyzed in Ricardo study, with the calculation starting from the first annual mileage [4]. First figure illustrates how LCV activity decreases over vehicle lifetime for all segments and second one represents the accumulated mileage that is performed depending on LCV activity, separately. Annual mileages during the first year are assumed depending on van types: 22,000 km (small segment) 24,000 km (compact segment) and 26,000 km (large segment). Moreover, their accumulated lifetime mileages that are considered equal both for ICE+HEVs and EVs in the same segments are shown in the table.

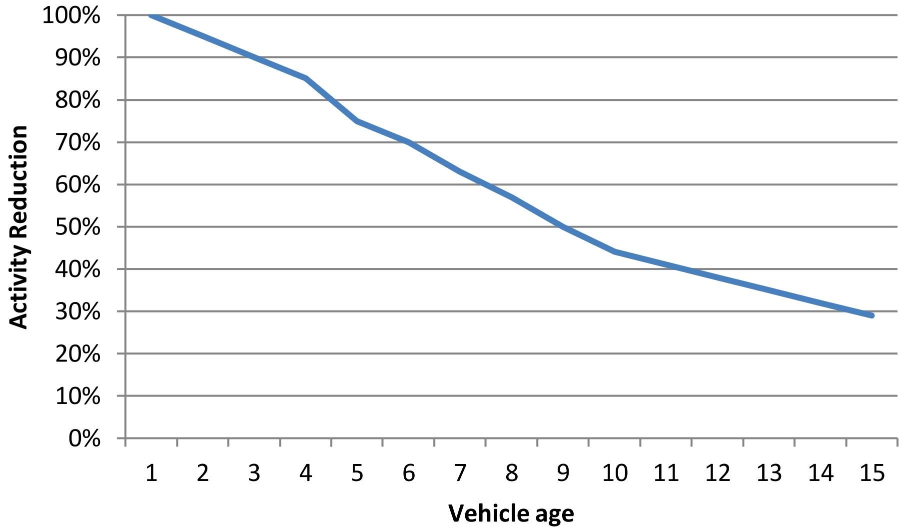



**Figure 28 - Activity Profile**

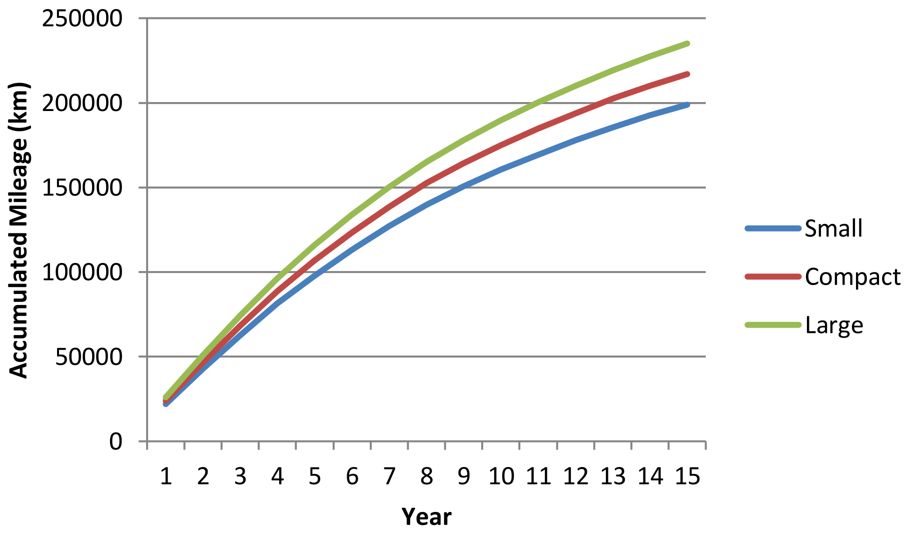



**Figure 29 - Mileage Profile**

| Segment | Small | Compact | Large |
|---|---|---|---|
| **Lifetime Mileages (km)** | 198880 | 216960 | 235040 |

**Table 48 - Lifetime Mileages**

### 5.1.6 Fuel and Energy Costs

Total Cost of Ownership analysis is highly affected by fuel and energy consumptions of different powertrains that determine their cost-effectiveness within the lifetime of a vehicle so that changing in petrol, diesel and electricity prices has a significant impact on their economy. However, instability of fuel prices make it difficult to have a precise assumption over the coming years, for this reason, petrol and diesel prices are collected from CE Delft study in euro/liter by converting it in euro/megajoule and electricity costs that have adjusted from PRIMES-TREMOVE module are converted from Euro/kWh to Euro/megajoule for the target years of 2025 and 2030 [59] [60]. Then, fuel and energy consumptions are calculated for each powertrain and segment by using the DIONE Fuel and Energy Cost module with WLTP-Real world conversion factors of each powertrain taken from Ricardo study. The table demonstrates the petrol, diesel and electricity prices used in the calculation of selected LCVs fuel and energy costs.

| 2025 | Petrol | Diesel | Electricity |
|---|---|---|---|
| **Fuel Price** | 1,52 | 1,37 | 0,209 |
| **Unit** | €/l | €/l | €/kWh |
| **Energy price** | 0,0432 | 0,0367 | 0,0581 |
| **Unit** | €/MJ | €/MJ | €/MJ |

| 2030 | Petrol | Diesel | Electricity |
|---|---|---|---|
| **Fuel Price** | 1,63 | 1,48 | 0,212 |
| **Unit** | €/l | €/l | €/kWh |
| **Energy price** | 0,0463 | 0,0397 | 0,0589 |
| **Unit** | €/MJ | €/MJ | €/MJ |

**Table 49 – 2025 and 2030 Fuel and Electricity Prices**

### 5.1.7 Insurance and Maintenance Costs

LCV insurance costs are provided from AXA insurance company based on the year of 2020 by setting mileage more than 20,000 km for diesel powertrains of each segment. [61] Similarly, data related to maintenance costs are collected from the van service report, Mopar, to clarify the difference of repair and servicing costs between van segments. [62] To sum up, the settings developed by Ricardo are converted for the assumptions of insurance and maintenance costs of e-LCVs regarding to years of 2025 and 2030. It is noticeable that electric vans which have fewer moving parts are much more cost-effective with respect to gas-powered vans in terms of vehicle maintenance. However, the average annual insurance costs for ICE-based vans are lower than alternative powertrains by taking into consideration that e-LCVs are fairly new to the market without historic data and easy to damage but the gap between insurance costs of conventional and e-LCVs is likely to be narrowed as battery costs will be coming down up to 2030.

### 5.1.8 Taxes

Tax benefits granted for e-LCVs are included in the O&M costs in order to quantify ownership tax, registration tax and expenses arising from urban access regulations such as parking fees and LEZ penalties by taking into account an average of these benefits on EU member states which are selected in previous part 3.3. According to this data, most EU countries have decided to exempt low- and zero- emission vehicles from taxes on vehicle acquisition and ownership until 2024 and partly, there is no any specific tax for the first 10 years after the acquisition of e-LCVs in some EU member states. Therefore, the amount of registration and ownership taxes are quantified by using EU Commission study of Transport taxes and charges in Europe and costs of different type of taxes (registration tax evaluated as one-time costs is divided into 15-year lifetime) are determined based on discount rate for which e-LCVs 50% in 2025 and 75% in 2030 with respect to conventional vans, then, the tax cuts up to 75% and 90% are similarly applied for LCVs with PHEV/REEV powertrains for the respective years of 2025 and 2030. Other expenses related to parking fees and LEZ charges are defined based on data explained in the section 3.1.2. [63]

| Segment | Tax / Powertrain Type | Ownership | Registration | Parking/LEZ |
|---|---|---|---|---|
| Small | CI+Hybrids | 120,00 € | 100,00 € | 120,00 € |
| | SI REEV | 90,00 € | 75,00 € | 90,00 € |
| | BEV | 60,00 € | 50,00 € | 60,00 € |
| Compact | CI+Hybrids | 220,00 € | 120,00 € | 150,00 € |
| | SI PHEV | 165,00 € | 90,00 € | 112,50 € |
| | BEV | 110,00 € | 60,00 € | 75,00 € |
| Large | CI+Hybrids | 350,00 € | 200,00 € | 200,00 € |
| | SI REEV | 262,50 € | 150,00 € | 150,00 € |
| | BEV | 175,00 € | 100,00 € | 100,00 € |

**Table 50 – 2025 Tax and Other Expenses**

Same activity reduction rate is implemented on annual total O&M costs including insurance, maintenance and relevant taxes in order to find aggregated O&M cost within a useful life time of 15 years. The table provides a comparison of completed O&M costs for each powertrain type and segment developed for this study.

| Model | PWT | Tax Expenses | Maintenance | Insurance | 1-year |
|---|---|---|---|---|---|
| **Small** | CI+Hybrids | 340,00 € | 584,00 € | 672,00 € | 1.596,00 € |
| | SI REEV | 255,00 € | 546,00 € | 677,00 € | 1.478,00 € |
| | BEV | 170,00 € | 391,00 € | 693,00 € | 1.254,00 € |
| **Compact** | CI+Hybrids | 490,00 € | 647,00 € | 744,00 € | 1.881,00 € |
| | SI PHEV | 367,50 € | 602,00 € | 750,00 € | 1.719,50 € |
| | BEV | 245,00 € | 432,00 € | 767,00 € | 1.444,00 € |
| **Large** | CI+Hybrids | 750,00 € | 908,00 € | 1.044,00 € | 2.702,00 € |
| | SI REEV | 562,50 € | 818,00 € | 1.102,00 € | 2.482,50 € |
| | BEV | 375,00 € | 635,00 € | 1.127,00 € | 2.137,00 € |

**Table 51 - 2025 O&M Costs of TCO Analysis**

## 5.2 Results of the Total Cost of Ownership Analysis

TCO analysis calculations are carried out by specified assumptions by taking into account typical costs for all LCVs, comparing e-LCVs to conventional vans with hybrid technology over the entire vehicle lifetime starting from the target years of 2025 and 2030. The results show that even if higher technology costs cause higher retail price with base vehicle costs, the TCO for all pure electric vans is compensated by energy cost savings within 15-year lifetime. Also, CI+HEV vans have relatively larger O&M costs for each segment as it is assumed that electric vans are partly exempt from expenses such as taxes and operation costs thanks to incentivizing mechanisms on e-LCVs assumed to be continued until 2030. In the first part, composition of parameters included in the TCO analysis are illustrated comparing different versions of vans in terms of powertrain type and segment in euro by indicating operating cost per kilometer. Payback analysis is conducted to detect break-even points of the TCO based on the amount of benefits and/or additional costs for all LCV segments.

### 5.2.1 2025 TCO Analysis Results

- **Small LCVs**

As it can be seen from the figure, vans with battery electric powertrain show the lowest TCO having 18,5 cents per km with respect to REEV version (20,7 cents/km) and diesel one (19,8 cents/km) due to energy cost benefits and significantly lower O&M costs. However, small vans with REEV powertrain are less competitive against CI+HEV in spite of they allow more fuel saving in the end of a 15-year lifetime.

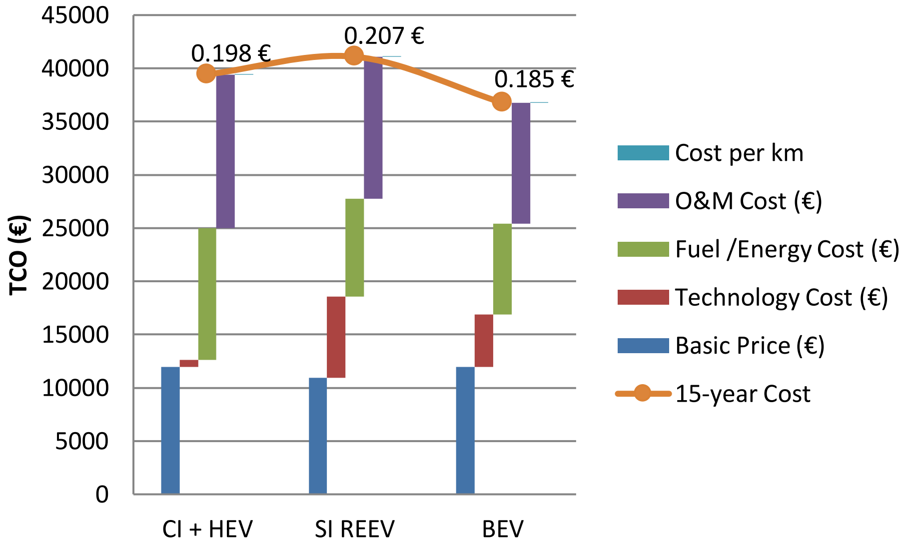



**Figure 30 - 2025 TCO Analysis (Small Vans)**

- **Compact LCVs**

Differently from small segments, PHEV powertrain type is analyzed in terms of total ownership costs for compact vans. Similarly, BEVs present lower total cost of ownership by resulting in better competitive position than HEV and PHEV. But in this time, compact LCVs with PHEV powertrain infrastructure are more cost-competitive than vans having the ICE powertrain.

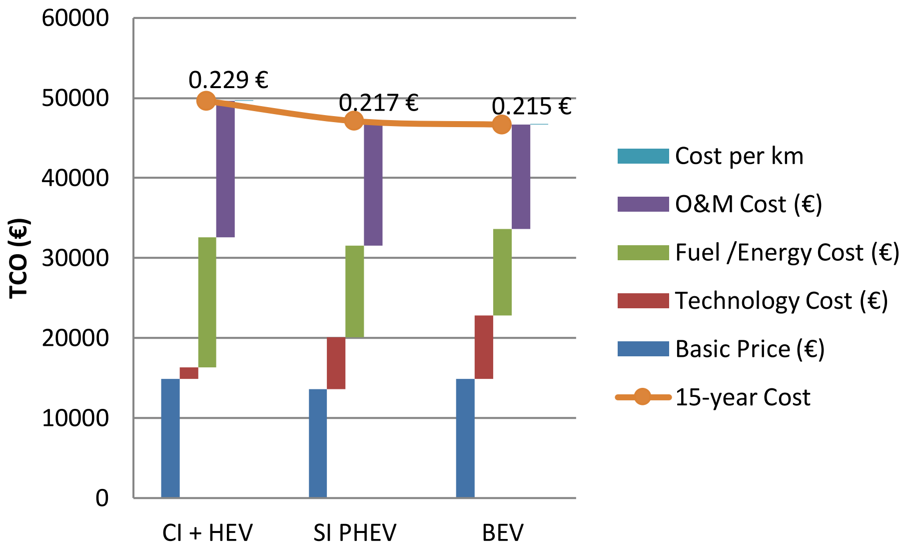



**Figure 31 - 2025 TCO Analysis (Compact Vans)**

- **Large LCVs**

Large LCVs have TCO varying between 30 and 32 eurocents per km that SI REEVs offer a TCO of 2 cents/km lower than BEV one and about 16 cents lower than CI+HEV depending on the assumptions of TCO model. As the distance driven by the vans increases, differences in TCO between ICE based vans and e-LCVs are becoming more evident, for instance, the saving on fuel cost is much higher for BEV and REEV powertrain that compensate the effect of higher battery cost in a long-term.

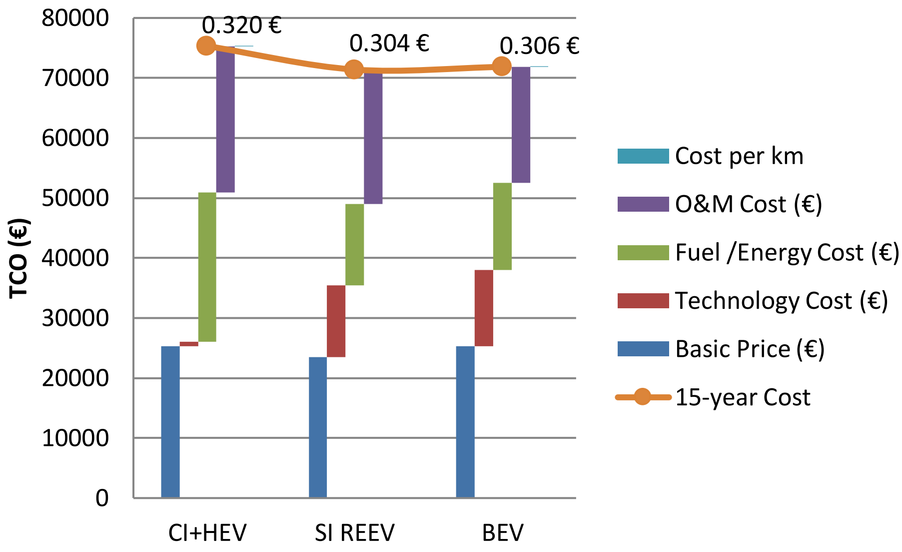



**Figure 32 - 2025 TCO Analysis (Large Vans)**

### 5.2.2 2030 TCO Analysis Results

Figure 30 illustrates comparisons of total cost calculations for each powertrain and segment separately from the customer perspective in the year of 2030. In spite of its high battery costs, electric vans keep up its competitive position thanks to its fuel effectiveness and lower O&M costs. It can be interpreted that SI REEVs are not expected to be financially more attractive than hybrid and electric vans for small segments. On the other hand, LCVs with range extenders are supposed to be more cost-competitive with respect to other powertrains in large segments. Still, Plug-in hybrid compact vans are less costly than mild hybrid one, saving almost 10 cents per km.

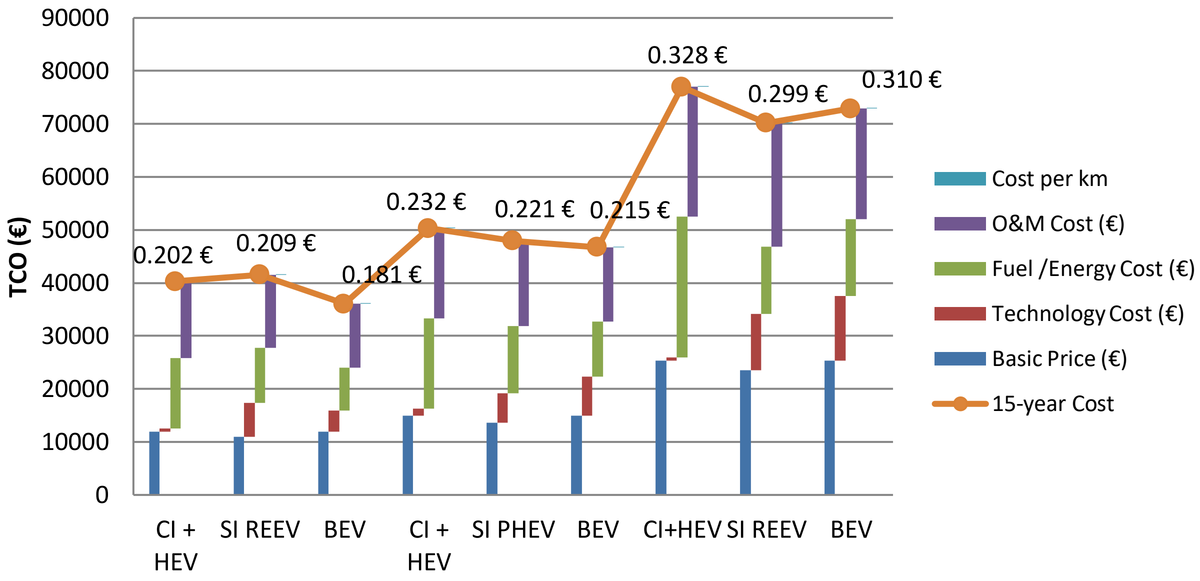


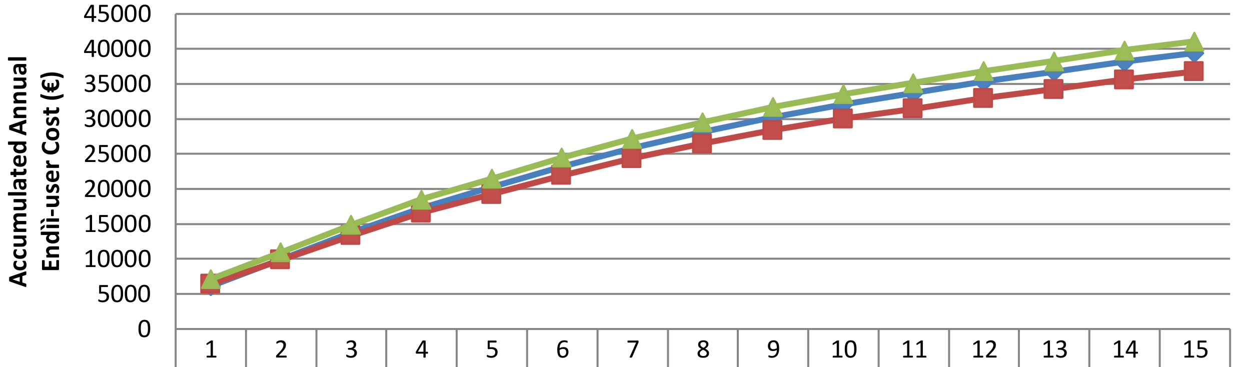

**Figure 33 - 2030 TCO Analysis Results**

## 5.3 Payback Analysis

The purpose of payback analysis is to establish cumulative cost differences at each point in time for each LCV segment and powertrain by using the default assumptions over a total LCV lifetime of 15 years. As LCV end-users who are generally companies and fleet operators base upon their buying decisions on break-even points associated with positive and negative costs, for this reason, payback analysis is an important element to invest in a more efficient LCV.

- **Small LCVs**

The figure below shows the effect of TCO for small vans that BEVs are able to break even with Hybrid powertrains in the second year after purchasing while SI REEVs do not surpass the total cost difference with small ICE vans within 15 years.

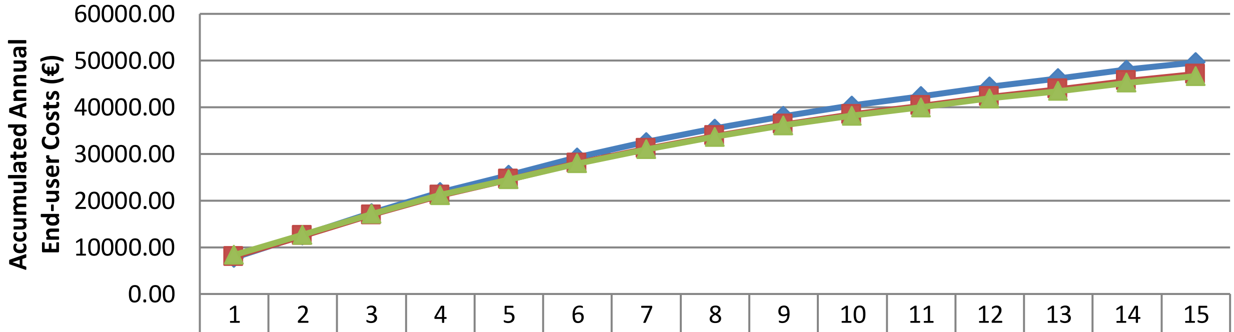



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CI + HEV | 6124. | 9951. | 13755 | 17286 | 20267 | 23226 | 25852 | 28173 | 30287 | 32097 | 33691 | 35323 | 36739 | 38193 | 39432 |
| BEV | 6423. | 9863. | 13362 | 16583 | 19246 | 21967 | 24366 | 26464 | 28408 | 30052 | 31460 | 32971 | 34248 | 35627 | 36772 |
| SI REEV | 7129. | 10982 | 14896 | 18500 | 21483 | 24527 | 27211 | 29560 | 31735 | 33574 | 35153 | 36843 | 38272 | 39812 | 41091 |

**Figure 34 - Payback Analysis of Small Vans**

- **Compact Vans**

As it can be seen from the table that SI PHEVs and BEVs reach both a break-even point with compact mild hybrid vans in the second and third life year, respectively. Over 15 years, a compact van with hybrid powertrain causes a total additional cost of €3000 with respect to alternative electric LCVs.

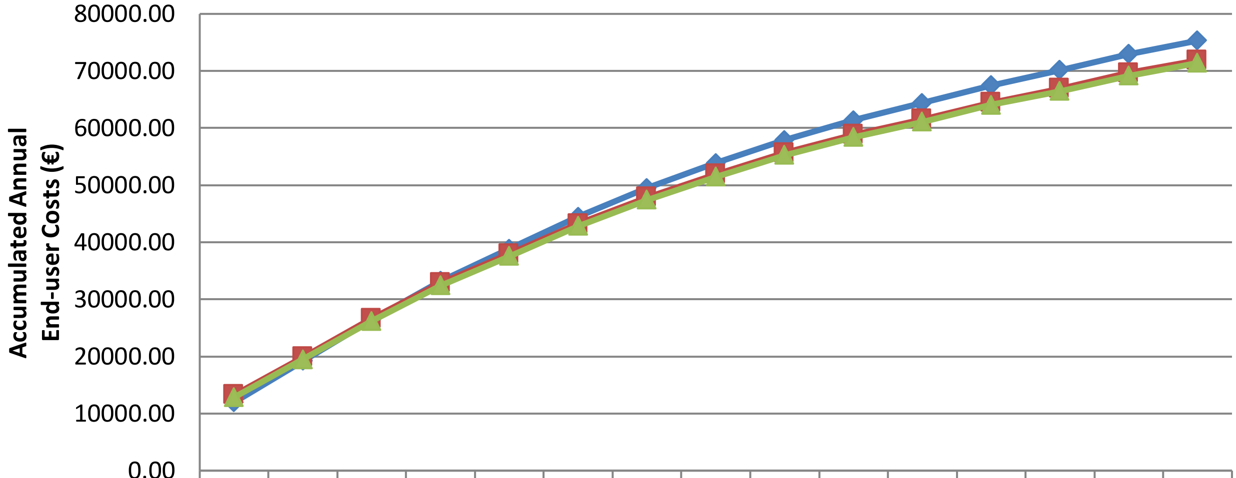



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CI +HEV | 7769. | 12572 | 17354 | 21789 | 25529 | 29249 | 32547 | 35462 | 38119 | 40391 | 42390 | 44442 | 46220 | 48051 | 49609 |
| SI PHEV | 8011. | 12457 | 16955 | 21102 | 24549 | 28047 | 31136 | 33844 | 36342 | 38461 | 40289 | 42228 | 43877 | 45637 | 47106 |
| BEV | 8343. | 12674 | 17103 | 21171 | 24518 | 27962 | 30994 | 33638 | 36098 | 38172 | 39938 | 41853 | 43461 | 45218 | 46668 |

**Figure 35 - Payback Analysis of Compact Vans**

- **Large LCVs**

Battery costs can be considered as a large determinant of retail price of large e-LCVs because of its higher capacity but these technology costs are covered by the lower insurance costs and energy consumptions. The figure shows that break-even points of e-LCVs are in the third and fourth year for large vans with SI REEV and BEV powertrains, respectively.

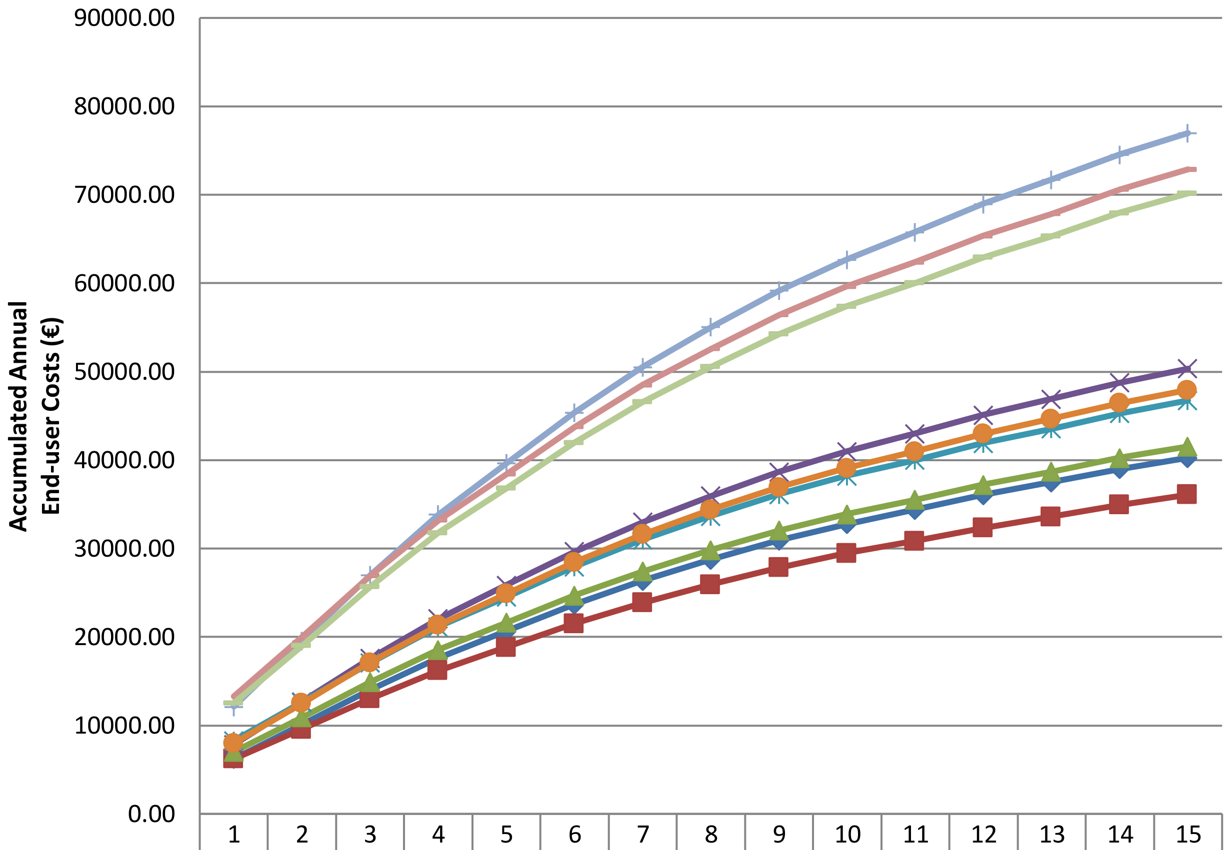



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CI +HEV | 11963 | 19224 | 26472 | 33188 | 38838 | 44475 | 49471 | 53880 | 57907 | 61346 | 64362 | 67474 | 70163 | 72949 | 75311 |
| BEV | 13245 | 19842 | 26633 | 32856 | 37944 | 43225 | 47865 | 51899 | 55671 | 58839 | 61514 | 64457 | 66908 | 69626 | 71852 |
| SI REEV | 12844 | 19456 | 26224 | 32439 | 37547 | 42811 | 47443 | 51481 | 55241 | 58408 | 61101 | 64030 | 66485 | 69175 | 71392 |

**Figure 36 - Payback Analysis of Large Vans**

- **2030 Payback Analysis**

Depending on payback analysis, the competitive gap between pure electric small vans and micro hybrid one is getting wider that small electric LCV save almost €1800 after 5 years. By contrast, both BEVs and PHEVs in compact segments break-even with the diesel version in the second year of the vehicle. Likewise, large SI REEVs become more competitive by reaching break-even point one year earlier than 2025 with its diesel counterparts.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CI + HEV | 6207. | 10121 | 14007 | 17615 | 20664 | 23687 | 26378 | 28751 | 30918 | 32768 | 34400 | 36066 | 37514 | 38997 | 40262 |
| BEV | 6213. | 9604 | 13043 | 16210 | 18836 | 21511 | 23877 | 25943 | 27860 | 29477 | 30868 | 32352 | 33609 | 34959 | 36083 |
| SI REEV | 7009. | 10938 | 14906 | 18568 | 21615 | 24702 | 27435 | 29827 | 32040 | 33911 | 35528 | 37238 | 38695 | 40245 | 41541 |
| CI +HEV | 7830. | 12711 | 17565 | 22068 | 25870 | 29645 | 33004 | 35964 | 38671 | 40979 | 43012 | 45094 | 46900 | 48756 | 50336 |
| BEV | 8274. | 12627 | 17066 | 21147 | 24513 | 27966 | 31014 | 33670 | 36144 | 38225 | 40002 | 41921 | 43536 | 45293 | 46746 |
| SI PHEV | 7981. | 12534 | 17122 | 21358 | 24892 | 28459 | 31621 | 34392 | 36949 | 39115 | 40993 | 42968 | 44656 | 46441 | 47938 |
| CI +HEV | 12134 | 19569 | 26982 | 33853 | 39641 | 45406 | 50531 | 55044 | 59175 | 62695 | 65786 | 68968 | 71721 | 74565 | 76979 |
| BEV | 13287 | 20003 | 26899 | 33223 | 38406 | 43769 | 48495 | 52599 | 56441 | 59662 | 62391 | 65377 | 67871 | 70623 | 72882 |
| SI REEV | 12510 | 19025 | 25682 | 31798 | 36833 | 42010 | 46581 | 50558 | 54269 | 57386 | 60044 | 62922 | 65340 | 67980 | 70159 |

**Figure 37 - Payback Analysis of all vans in 2030**

## 5.4 Sensitivity Analysis

In the sensitivity analysis, the impacts of different assumptions such as change in fuel and energy prices, mileage and financial incentives on TCO model are investigated in order to give an overview of results of several actions. For this purpose, the following figures illustrate how the competitive position of LCVs change according to parameters modified for the sensitivity of TCO analysis.

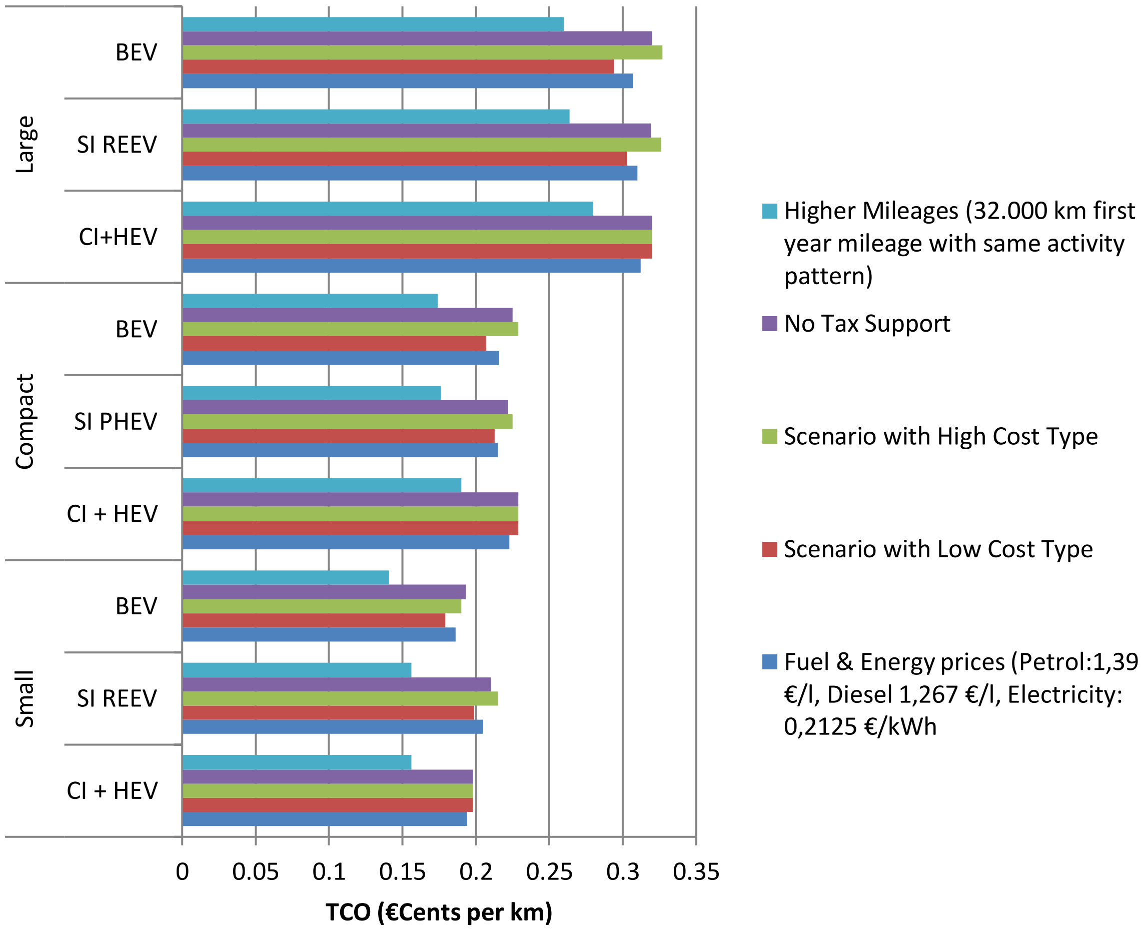



**Figure 38 - Sensitivity Analysis of TCO in 2025**

In the first case, an average distance of 32,000 km per year is analyzed by taking into account the same activity reduction rate over the 15-year lifetime of LCVs for each segment both in 2025 and 2030. It is clear that competitive gaps between hybrid vans and e-LCVs are larger due to lower fuel/energy cost of alternative powertrains. In small segments, TCO of SI REEVs per km driven is slightly less than micro-hybrid both for 2025 and 2030. Also, it is important to state that the more the overall mileage increases, the more the TCO of LCVs drops.

Another sensitivity analysis on the effect of fiscal incentives that encourage customers to acquire an e-LCV is conducted to evaluate the impact of competitive position of different powertrain types. The results show that electric vans are not so cost-competitive without the power of financial instruments such as exemption from registration tax or ownership tax, benefits of free parking and advantage of Low-emission-zones access compared to hybrid vans.

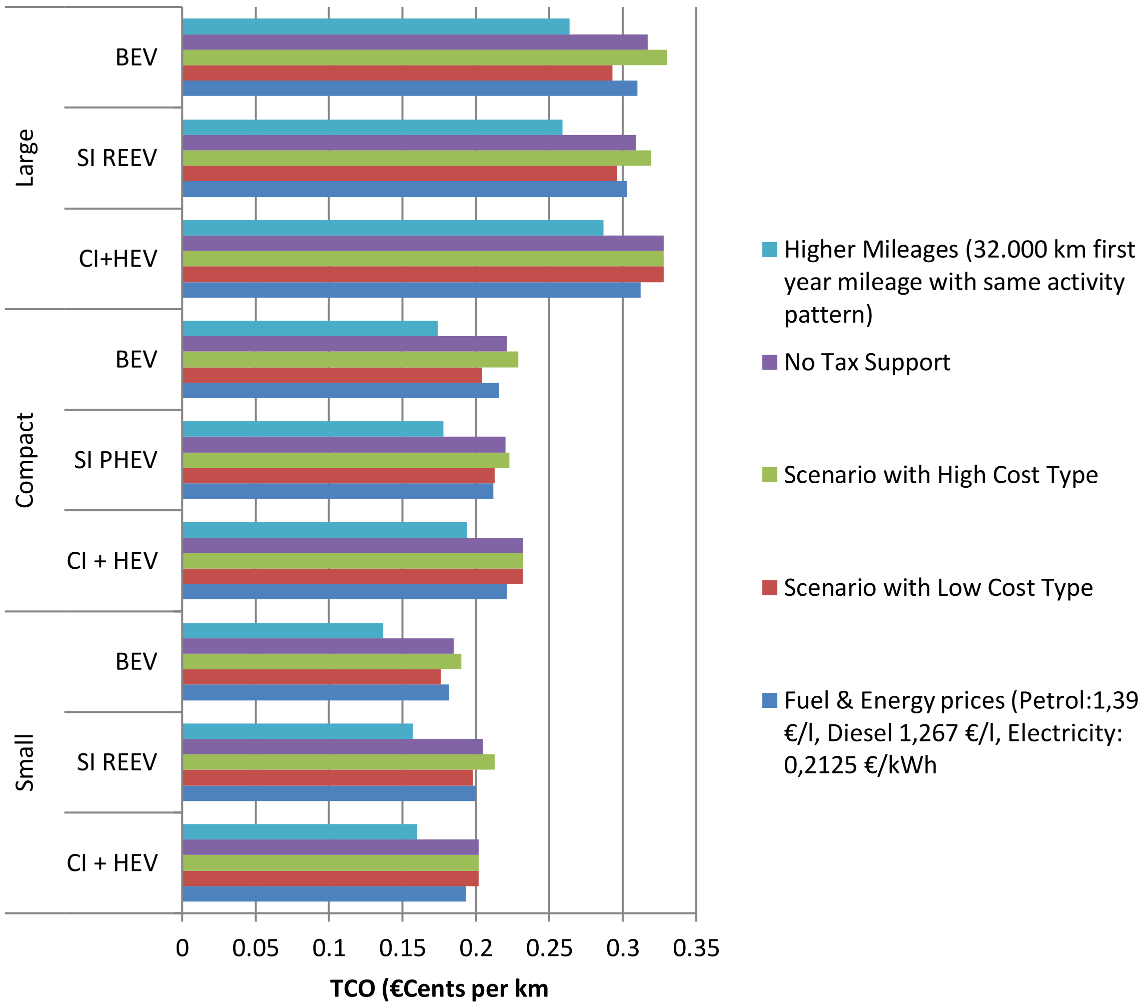



**Figure 39 - Sensitivity Analysis of TCO in 2030**

Battery cost sensitivity is analyzed in order to reflect possible limitations of electric vehicles technology uptake by taking into account high technology cost types of e-LCVs both for 2025 and 2030. Average total costs of ownership for e-LCVs are expected to increase in retail price due to additional technology costs depending on limitations such as recycling, source of critical materials and security. Figures shown below illustrate that e-LCVs become less interesting than hybrid one -except small electric vans. On the other hand, according to obtained results from the low cost scenario, all e-LCVs have a relatively low TCO compared to CI+HEVs.

Fuel and energy expenses of LCVs which have great importance for fleet operators and companies are calculated by taking into consideration average prices of the last

4 years and the last 6 years, as illustrated in market analysis section 2.6, for petrol/diesel and electricity costs, respectively. Even though petrol and diesel costs are assumed lower by setting higher electricity price with respect to the default case, small segment e-LCVs still save almost 10 eurocents per km compared to its micro-hybrid version. However, it can be seen that the competitive gaps between e-LCVs and conventional vans for compact and large segments are smaller in consequence of higher electricity costs.

# 6 CONCLUSION

Although there are several aspects of the LCV market to be stressed, the key findings are summarized with the following conclusions:

- **LCV Segments and Powertrain Types:**

Small vans: In this segment, LCVs are generally built as a derivative of a passenger car sharing the same production platform but differently having a loading space in the rear of the vehicle with higher gross vehicle weight. Battery electric powertrain solutions are best-suited to small-sized vans in terms of cost-savings and environmental impacts with proven sensitivity analysis of total cost of ownership in varying modifications. On the other hand, extended range electric vans with SI-powered engine have slightly higher TCO compared to micro-hybrid diesel version in all cases, except if they have driven more than 32.000 km per year with assumed activity pattern. However, it can be considered that REEVs may offer more generous payload and volume capacity than electric one. It should be noted that plug-in hybrid technology could be suitable for small segments as well but this powertrain type is analyzed for compact segment for the sake of the simplicity of the analysis. On the other hand, for this segment, it is approved that pure electric small vans have a much bigger effect in lowering emissions even though keeping their market shares low.

Compact vans: This segment of LCVs requires special attention due to their different volume, height and payload characteristics with respect to small vans. As a consequence, they have a much longer development and production cycle compared to passenger cars. For this reason, the use of LCV platforms in cooperation with other manufacturers or the same LCV portfolio of brands is more common in compact, midsize and large segments having typically higher product cycle. In order to comply with specific emission targets by taking into account its lighter weight, mild-hybrid powertrain with other technology options is implemented on compact segment vans. However, PHEVs and BEVs demonstrate that they are more cost-effective options related to TCO analysis over the period of 2025.

Large vans: Large segment vans dominate the commercial van market with mid-size segment by reflecting medium-heavy duty truck characteristics having highest gross weight, size (pan area and volume), emission level and capacity (seats, volume and retail price) compared to regular LCVs. Especially as online retail purchases increase during Covid-19 pandemic period, they have a great importance in delivering goods to their final destination, defined as last mile logistics, both for passenger and freight transport [64]. The present TCO analysis shows that high technology cost of e-LCVs can be compensated for by fuel/energy saving as well as O&M and fiscal benefits compared to diesel one after 2025. But, in this segment again, longer charging times and limited maximum payload due to presence of larger battery packs put pure electric large vans at a disadvantage with respect to diesel equivalents.

- **Customer's Point of View**

Light commercial vehicles play a significant role for small and medium-sized enterprises (SMEs) and sole trader sector, as described in the section 2.3, by contributing to the European economy and social development. The European light commercial vehicles market has been growing with an increase in the demand of e-commerce and e-LCVs which provide transport solutions for the digitalization of distribution network and logistics in business with more fuel-efficient powertrains.

As LCVs have mostly different market dynamics influenced by both technical and economic characteristics, fleet operator managers or sole traders base purchasing decisions mainly on payload, charging time and pure electric driving range with TCO analysis for which alternative powertrains are able to break even within 5-7 years compared to conventional vans. However, the explained attitude is typically addressed to the customer portfolio that needs LCVs types that have to meet emission standards enforced with the low emission zones in city centers so the market share of e-LCVs could be less than anticipated if future legislations will not be stricter by including a large part of the cities. On the other side, the European countries with proposed prohibition on conventional vans and/or only allowed new sales of electric vans can change the rules of the game that give acceleration of widespread e-LCVs adoption by early 2030. In addition, purchase subsidies, fiscal supports such as tax exemptions and free parking benefits as well as the deployment of public charging infrastructure are important parameters to influence customer perception and purchase requisition for e-LCVs even though quantities of these characteristics are fluctuating country-by-country in Europe.

- **Manufacturer's Point of View**

Some of LCV manufacturers are already highly motivated to focus on production of electric vans, in this regard; PSA group can be given as an example that has an objective to launch a fully electrified LCV fleet by 2025. Timeline of fleet composition history between 2013 and 2030 shows that SI engines are likely to come back to the LCV market with range extender and plug-in hybrid solutions so that it could help reduce the dieselization along with the contribution of BEVs overall fleet.

Even though market shares of each LCV are assumed to remain unchanged by 2030, the customer's decisions to invest in different powertrain technologies and segments directly affect the ambitious goals for cutting CO2 emissions. For this reason, the expansion in e-LCVs market determines the course of future action for the adoption of the EU manufacturer based slope by ensuring rise in average vehicle mass for each class with a great contribution to emission reduction.

As it can be seen from the financial analysis results, there are no huge differences between different types of technology scenarios by 2025 due to lower profit margins of e-LCVs. However, the outcome shows a dramatic increase in the gap between the most likely scenario of HYBRID and extreme policy scenarios such as BEV, PHEV/REEV and ADVANCE in terms of profitability by 2030. As it is proved with the sensitivity of TCO analysis that battery electric vans are able to be cost-competitive after 2025, the higher penetration of vans with pure electric powertrains leads to higher profit margins accompanied by lower production costs for companies. However, it is better to keep the market share of PHEVs/REEVs close to BEVs between LCV groups in the post-2020 period by taking into consideration their lower upfront costs with respect to battery electric vans and customer demand. On the other hand, higher BEV deployment in fleet composition gives better results in terms of overachieving ZLEV benchmark for the target years so that stimulating the sales of battery electric vans to keep them in majority overall fleet make a great progress to cut emissions by obtaining ZLEV credits for the most challenging emission targets of 2030.

Overall, the development of LCV market with alternative powertrains depends on external conditions such as fiscal incentives, oil prices and electricity costs even though LCV manufacturers are able to overcome market barriers, as described in the section 3.3.1, by improving technical characteristics of e-LCVs associated with payload, charging time and driving range. This study gives insight to develop a CO2 emission compliance strategy with technical, economic and social analysis through fleet composition scenarios for different types of LCVs.

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