UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

ESCUELA TÉCNICA
SUPERIOR INGENIEROS
INDUSTRIALES VALENCIA

TRABAJO FIN DE MASTER EN INGENIERÍA INDUSTRIAL

ANALYSIS OF ELECTRIFIED POWERTRAINS' ROLE IN REDUCING LIGHT-DUTY VEHICLE GREENHOUSE GAS EMISSIONS IN MAJOR EUROPEAN COUNTRIES

AUTHOR: FERRAN CLEMENTE RODRIGO

SUPERVISOR: PROFESSOR JOHN B. HEYWOOD - DR. ASHLEY NUNES

SUPERVISOR: PROFESSOR CARLOS MARÍA ÁLVAREZ BEL

Academic year: 2018-19

Acknowledgements

I feel very fortunate to have had this extraordinary opportunity. To work on my master thesis in such an inspiring environment as MIT is a privilege and I will always be grateful. However, any of this would be possible without the people whom I would like to thank.

First and foremost, I want to express my very great appreciation to Professor John Heywood for his extremely valuable and constructive advices. With his life-long wisdom and extensive experience in the field, he has guided me through the accomplishment of this work. During these months, he offered me great independence to develop my research, stimulated my curiosity by raising new unthought issues and encouraged me unconditionally when most needed. I am deeply thankful not only for teaching me the importance of paying attention to details and the culture of effort, but also exemplary human qualities as being humble, thoughtful and patient.

I wish to express my deep gratitude to Dr. Ashley Nunes for trusting me and making this possible. Without him undoubtably any of this would have never been possible. All his knowledge and ideas have been very constructive in shaping this thesis. I am glad for having the opportunity of meeting him personally and being influenced by all his knowledge and charisma.

I would like thank the MIT-Spain Inditex Sustainability Seed Fund and the Universidad Politécnica de Valencia teachers and members for supporting this international collaboration. Thanks to them I have had the chance to enjoy such a wonderful experience. I would like to mention as well all the administrative people who have supported and encouraged me during these months.

Finally, I feel words are not able to describe how much I am grateful to all my family, pair and friends. All their support and motivations has allowed me to overcome all obstacles in life and with them I would like to enjoy all the good moments yet to come. Specially to my parents, who are the source of inspiration and motivation which gives me strength to pursue my goals always.

Abstract

Although Electrified Vehicles (EV) represent a promising alternative for reducing road transportation related emissions, widespread adoption has been slow. Studying current tendencies in major Light-Duty Vehicle (LDV) European markets shows consumer’s current perception with regard to the deployment of the technology in its early stages. Identification of impediment barriers is an important first step towards minimizing sales disparities with current internal combustion engine vehicles (ICEV).

All efforts aiming EV adoption must be complemented with reliable information supporting expectations. Life Cycle Assessment (LCA) data can provide a broad awareness on how effective a technology can become while reducing GHG emissions and compare it to other existing. Depending on the source of energy to recharge plug-in electric vehicles or the vehicle components production process, the potential for reducing LDV emissions may differ significantly. Therefore, this work targets to analyze the environmental benefits of AFV adoption for a set of potential scenarios in major European countries. To use a robust and well-documented methodology is essential to support the reliability of results. Leveraging a simulation tool such as the Fleet Model developed in this research will serve to explore a wide set of scenarios. By performing sensitivity analysis on the parameters of interest it is possible to quantify the relative impact of each of the strategies studied for the different European countries.

Table of Contents

Table of Main Figures

List of Tables

List of Figures and Tables in the Appendix

List of Tables Appendix A

Table of Figures Appendix C

List of Tables Appendix C

Table of Figures Appendix D

List of Tables Appendix D

List of Acronyms

AFV	Alternative Fuel Vehicle
BEV	Battery Electric Vehicle
CI	Carbon Intensity
CO2	Carbon Dioxide
EU	European Union
EV	Electric Vehicles
FC	Fuel Consumption
FCEV	Fuel Cell Electric Vehicle
FM	Fleet Model
GHG	Greenhouse Gases
GWP	Global Warming Potential
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
IR	Improvement Rate
LCA	Life Cycle Assessment
LCV	Light-Commercial Vehicles
LDT	Light Duty Trucks
LDV	Light-Duty Vehicle
OLT	Other Light Truck
PEV	Plug-in Electric Vehicle
PCP	Public Charging Point
PHEV	Plug-in Hybrid Electric Vehicles
SUV	Sport Utility Vehicle
TTW	Tank-To-Wheels
VAT	Value Added Taxes
VKT	Vehicles Kilometers Travelled
WLTP	Worldwide Harmonized Light-Duty Vehicles Test Procedures
WTT	Well-To-Tank
WTW	Well-To-Wheels
ZLEV	Zero Level Emissions Vehicle

List of Acronyms

Chapter 1 - Introduction

I – Environmental challenges inherent in On-Road transportation

The transportation sector represents a significant source of greenhouse gas (GHG) emissions worldwide. Its impact has become more important as factors such as globalization, population increase or generalized wealth growth have encouraged its contribution in global emissions. Whether it is for a leisure trip or freight transportation, moving from one place to another has always been a need for human kind. Travelling is in our nature, that is why major actors must seek strategies to reduce its contributions to climate change. The greenhouse effect is responsible for absorbing part of the radiation from the Earth's surface, thus keeping it at temperatures above than what it would be if the atmosphere composition did not have the presence of GHG. Nevertheless, soaring concentrations of these gases will lead to a global warming effect potentially harmful.

At current rates, average world temperatures would increase to two degrees Celsius by 2036. Over the past decades GHG emissions related to transportation sector have skyrocketed reaching levels by 2010, two and a half times the ones in 1970 [1]. Going further transportation accounts for approximately a quarter of total anthropogenic greenhouse gases sent to the atmosphere. Therefore, limiting its impact is crucial for building a more environmentally respectful future and reducing the generalized temperature increase.

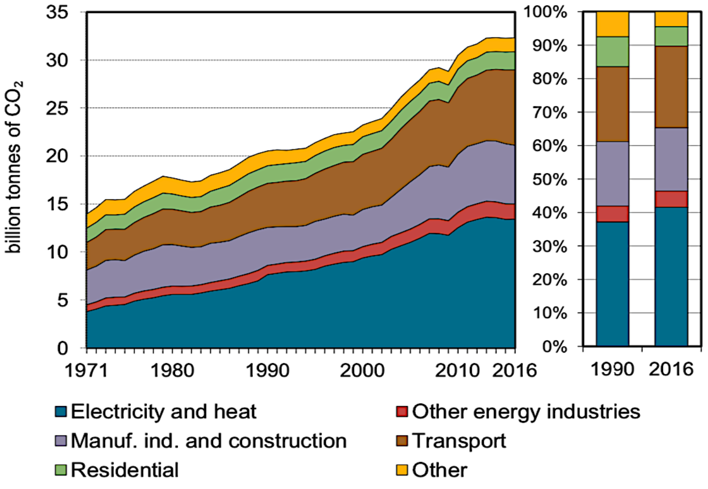

Figure 1: World CO2 Emissions by sector in billion tons of CO2 equivalent. Sector GHG emissions share evolution from 1990 to 2016 [2].

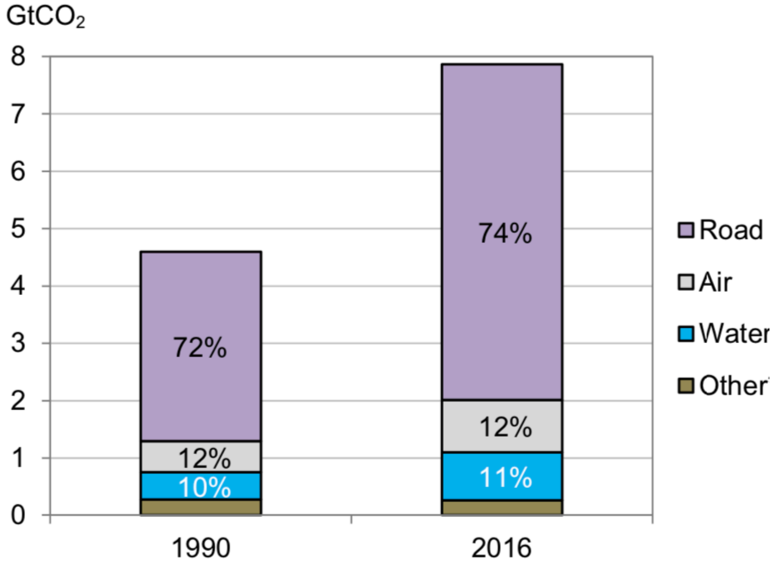

Figure 2: Global transport emissions by sub-category. Comparison between 1990 and 2016 situations [3].

Taking a closer look to the transportation sector, GHG emissions can be broken down into different sub-categories: Air, Water, Road transportation and Other means of transportation, which include rail and pipeline transportation. According to the latest available data, the total global GHG emissions linked to transportation activity are close to **8 GtCO2-eq**, which is mostly due to Road transportation. With an increasing share of **74%** in 2016, Road transportation is gaining relevance in GHG emissions. Hence the importance in taking action and reverting the current trend.

This thesis focuses mainly in the contribution of Light-Duty Vehicles (LDVs) in European countries. The objective is to assess the impact of several strategies aiming to reduce GHG emissions inherent to vehicle fleets. The transportation sector represents **20%** of total emissions in Europe, the share increases up to **27%** if international shipping and aviation are included. Road transportation represents **72%** of the total European Transportation sector. Going further, the road transportation percentage can be divided into the different on-road vehicle segments. This breaks down GHG emissions, identifying more precisely their origin.

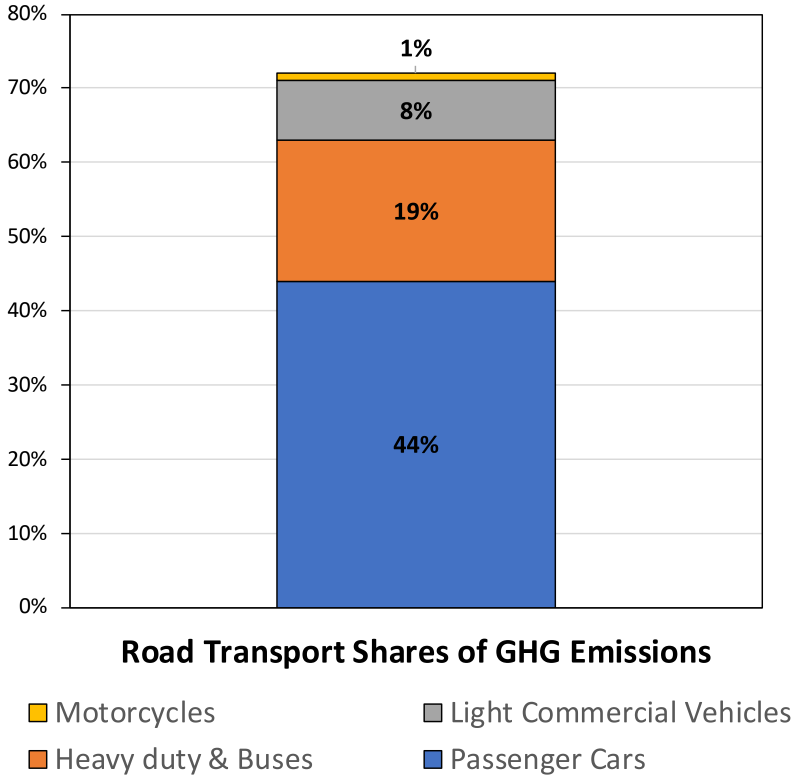

Figure 3: Share of road transport sector for total transportation sector GHG emissions for EU-28 in 2016 [4].

Passenger cars and Light Duty Trucks (LDT) constitute what is defined as Light-Duty Vehicles. Generally, it gathers all four-wheel vehicles commonly used with a weight below 3500 kg and a payload capacity up to 2000 kg. Segmentation weights may differ depending on the country and from US classification standards, but are quite homogeneous all over Europe. Greenhouse gas emissions of LDVs over the total Transportation sector are close to **52%**. This frames the prospective reach which strategies studied in this research have. It also puts into context the relevance of all the measures proposed with the ultimate goal of reducing GHG emissions.

Governmental and International organizations have set certain policies aiming to revert the existing trend. Since the early 2000s, the automotive manufacturers have been pushed gradually to shift towards greener vehicles. At the same time subsidies and preferential benefits encourage consumers to adopt Alternative Fuel Vehicles (AFV) rather than convention Internal Combustion Engine Vehicles (ICEV). Nevertheless, the market penetration rates of these greener technologies have been weighed down by diverse barriers of adoption. This implies AFV still present certain disadvantages which highlights its inconvenience in many daily situations. According to nowadays transportation habits, it is hard to imagine that technological improvements would be sufficient to overcome the barriers to adoption in the nearer term, suggesting a complementary change in society's travel behaviors for these new technologies to succeed.

II – Alternative Fuel Vehicles as a path towards greener mobility

Vehicles relying on non-fossil fuels have become a promising and effective solution to reduce tailpipe emissions. In parallel hybrid powertrains still rely on fossil fuels, but offer the possibility to incorporate electrified powertrains and attain substantial efficiency benefits. However, in this work Life-Cycle Assessment (LCA) of greenhouse gas emissions is used for the different vehicles studied, which includes vehicle production and the means of fuel or energy procurement. Taking into account full LCA gives a more complete picture about the real emissions impact of changing one technology for another. A brief description on the different existing technologies is presented to give a better understanding on their principle of operation and what is their role in the road transportation LDV sector.

a) Internal Combustion Engine Vehicles

For more than a century ICEV have represented the most reliable powertrain for means of transportation. Its widely spread refueling infrastructure and affordable costs have led the technology to be used all over the world. Oil prices have remained relatively affordable for users through recent times, though fuel taxes may differ from one region to another. The expected trend is to progressively rise in the coming years. The oil stock is assumed to cover the demand up to 50 years at current rates of supply and demand, giving at first sight a broad allowance to be replaced [5]. Nonetheless, their GHG emissions are responsible for an important contribution to global warming, as seen previously. That is why the change towards more sustainable technologies has to take place with relative urgency, to minimize all potential resultant effects.

The main reason ICEV pollute is due to their principle of working. Their propulsion energy is obtained by the combustion of hydrocarbons. Thanks to its powertrain structure it is able to transform the chemical energy contained in fuel molecules into mechanical motion. The air utilized is collected by the intake and mixed with fuel meeting the necessary conditions to allow ignition to happen in the combustion chambers. Generally, by means of four-strokes cycles [6] part of the energy released in the combustion chambers is transmitted to the crankshaft which linked to the transmission axe by a universal joint, distributes the power to the driving wheels. As a product of combustion, the exhaust gases are released to the ambient. These gases are mainly composed of water vapor, CO2 - and in fewer concentrations' methane and nitrous oxide - which are in fact most common greenhouse gases in the atmosphere. GHG emissions are measured in grams of CO2 equivalents (gCO2eq), which is based on global warming potential (GWP) of each of the gases contributing to the effect with regard to CO2.

Regular ICEV are broadly divided into gasoline and diesel engines. Both work under the same principle but use different fuels. The essential difference between them is their octane / cetane number and by consequent the compression ratios at which they operate. Each contribute in different manner to GHG emissions. Both having similar amount of energy per mass unit, diesel fuel is a 14% more dense. In other words, energy density from diesel fuels is higher meaning in terms of fuel consumption, diesel engine vehicles are more efficient. Nonetheless, diesel fuel has a higher content of gCO2eq per volume unit, making their GHG emissions slightly higher in vehicles of comparable size.

b) Hybrid Electric Vehicles

Hybrid Electric Vehicles (HEV) are born as a technological advance from ICEV. They keep a compromise with the utilization of an internal combustion engine supported by an electrical motor and battery. In some cases, electrical power unit is only used for allowing the engine to shut-off instead of idling, which represent what are known as mild hybrid vehicles or micro hybrids. Their electrical unit is not sufficient to power the vehicle without the support of the internal combustion engine. On the other hand, full hybrids do have sufficient power to run during periods of time at low speeds with their electrical unit alone. At the same time, they can offer better fuel-economy reaching in some cases a fuel consumption reduction up to 35% with respect similar size gasoline engine vehicle by using their electric motor and regenerative breaking energy recovery [7]. During the following analysis HEV are considered only full hybrid vehicles, whereas mild hybrids are contributions to the fuel-economy improvement of ICEV.

The technology was invented early in the twentieth century, but the first broad appearance of an HEV in a passenger car market was in 1997 with the well-known Toyota Prius Hybrid in Japan, where it has become very popular among consumers. Since then, over 12 million units have been sold worldwide [8]. Hybrid technology embodies the cutting edge in GHG emissions reduction related to the road transportation sector, as it begun the shift to more environmentally respectful Light-Duty Vehicles. It provided a starting point of familiarization towards the introduction of electrified powertrains.

c) Plug-in Hybrid Electric Vehicles

Going a step further than HEV, Plug-in Hybrid Electric Vehicles (PHEV) have very similar principle of working. Their main difference is while the first hybrid technology benefits from their internal combustion engine to charge their battery when it is not being used, PHEV have a larger battery capacity and must be recharged by connecting them to the electrical grid or an external source of power. PHEV are meant to prioritize using their electrical power unit. However, they still profit from the benefits of having an internal combustion engine when needed and may run with it if recharging is not available. This duality which is broader than HEV, makes PHEV very convenient in terms of compromise between fuel-efficiency and flexibility of use in a wide range of situations.

Depending on the electrical range of travel PHEV are categorized. This gives an idea on the utility factor, which represents the percentage of total miles driven using only the electrical powertrain. Typically, PHEV are considered AFV as their primary source of energy is intended to be electricity, even if eventually they rely on fossil fuels. The first commercial model going to series production came in 2008, but due to its high costs compared to similar gasoline engines the technology did not arrive at general public until 2010 [10], aided by incentives to encourage their adoption.

d) Battery Electric Vehicles

Being totally fossil fuel independent during their utilization, Battery Electric Vehicles (BEV) represent a clear advantage with respect the other powertrain technologies regarding tailpipe emissions. Their motion is completely powered by one or more electric motors. The distance travelled per full recharge, also known as range, is mainly determined by their battery storage capacity and its relative vehicle size. Initial perception may suggest it is an absolutely green technology, thus BEVs should be conceived as an emissions displacement vector. Electricity production is always linked to a certain amount of emissions at its origin. The analysis conducted in this work includes LCA data for the different sources involved in energy production. However, totally electrical Light-Duty Vehicles are expected to become an important factor to reduce GHG emissions worldwide. Yet to be able to effectively replace combustion engine vehicles, major strategies for BEV adoption must be able to overcome existing obstacles, which from a consumer point of view is revealed as higher purchase price and recharging inconvenience.

Therefore, the sales share penetration may differ significantly from one country to another and is commonly linked to the amount of incentives available. The driving range is also perceived as a problem for their adoption, but recent battery development has led to significant progress in that field. The technology is well known since the nineteenth century, when the first electrical motor was tested for propelling a car in 1827. Notwithstanding its great success in the very early stages of the automotive industry, it was quickly relegated by internal combustion engines. The technical improvements in gasoline engines and their more affordable purchase and operating costs ended up by overwhelming electric vehicle sales after 1910 [11]. After the technology was forgotten, BEV had to wait almost a century until 2008 to be reintroduced in LDV markets with the Tesla Roadster model. It became the first production all-electric lithium-ion battery vehicle and had surprising range of 320 km per charge. By virtue of advances in battery technology and better awareness of climate change, BEVs started gaining attention. Incentives and environmental policies were the main causers to have them back in the market. Further on this work analyzes in more detail their current situation in major European countries.

e) Fuel Cell Electric Vehicles

Hydrogen powered vehicles are envisioned as a promising solution to replace ICEV. Fuel cells are able to recombine hydrogen with other molecules to exchange Oxygen atoms, as a result of the spontaneous redox reaction which give as products a current of electrons and water molecules [12]. Fuel Cell Electric Vehicles (FCEV) benefit from this chemical reaction to supply with electricity its powertrain. The technology and its applications for the automotive industry are known for a couple of decades, but it has always remained a prototype option until recently.

Nowadays, the non-competitive high costs of hydrogen linked to a refueling infrastructure in its very early stages of development, make it hard to predict future rate of adoption of FCEVs. To procure clean and meaningful hydrogen production is the main focus in order to enhance this powertrain technology in its first phase of introduction to global LDV markets. The commercialization of first models is being introduced gradually and vehicles prices are expected to go down. It is estimated costs will reach the 50% of their current value, by the time FCEVs reach 100.000 units on the road [13]. First available model for consumers was Hyundai Tucson in 2014. However, a reduced number of prototypes were already set in the road the decade earlier as part of corporate leasing plans. Nowadays, the total number FCEVs on the road is 2500 vehicles, show how much progress is still needed to spread this technology.

f) Other existing Alternative Fuel Vehicles

Other existing alternatives to conventional ICEVs are presented in this section. However, their potentials for reducing total fleet GHG emissions being more modest, they are not considered in the scope of this research, though under given conditions they manage to reach effective reductions.

- **Biofuels:** Several vehicle powertrain technology leverage fuels produced from biomass. Currently, a wide range of biofuels exist, extending the variability of future technology developments in this particular field. However, the environmental benefits from adopting them are disputed. Due to the extensive use of land required to cultivate them and the natural environmental impacts they have, biofuels are often criticized for having an overall negative environmental impact [14].

- **Liquified Petroleum Gas:** Some vehicles are propelled using liquified petroleum gases (LPG) such as propane or butane. These vehicles are considered clean as they can achieve effective GHG emissions reductions of a 15% in average. Some countries - such as Turkey, South Korea, Poland, Australia and Italy - have supported the LPG vehicle adoptions in order to mitigate LDV GHG impacts, gathering almost half the total in-use vehicles worldwide, using this technology.

- **Compressed Natural Gas:** They represent another existing AFV technology. Using compressed natural gases (CNG), generally methane, these types of vehicles obtain an average 25% reduction in GHG tailpipe emissions with respect their internal combustion engine peers. It is also important to underline the use of highly pressurized tanks to store the natural gases, which are entirely replaced when refueling the vehicle. Nonetheless, this entails a threat in case they are accidentally spilled.

III – Contribution and work structure

The goal of this work is to assess the role of electrified powertrains in major European countries. It aims to give well-founded guidance of the different strategies regarding Light-Duty Vehicles which will potentially lead to important GHG emissions reduction. Analyzing the recent adoption in each of these markets establishes a starting point to understand the present state we are at. This research also summarizes the policies adopted in the countries studied to influence automotive manufacturers and consumers to shift towards greener powertrain technologies, giving an assessment on the main factors motivating the change. The work focuses on presenting future strategies which represent future paths towards a more environmental respectful LDV fleet.

A computational Fleet Model (FM) is developed and adapted for each of the analyzed countries. Inspired on the logics behind different scenario calculations reports, the interest of this model is that it combines reliable data regarding LDV fleets in each of the countries considering a wide number of variables that have influence in the final amount of emissions. It not only includes market sales by segment as well as emissions associated to vehicle production and fuel supply, and also grid electricity production data, which with LCA data is interpreted as its related emissions. Assuming several EV penetrations levels, balancing the relative proportions of all electrified powertrains market shares and projecting the electricity generation mix in different ways, the FM can explore an extensive range of scenarios. This helps to quantify the environmental effects of achieving each particular strategy and compare them to a thoughtfully constructed reference scenario. Nonetheless the amount of detail included in the model, requires a solid set of assumptions to run the calculations. It is impossible to fully estimate the behavior of each variable and their interactions. Therefore, the results set guidance but are subject to a certain degree of uncertainty. However, this thesis conducts this type of analysis to a depth of feature which is not readily available for the studied countries. It uses a consistent methodology for total

LDV emissions calculations and gives clearance on the effectiveness that different strategies have to mitigate climate change.

Chapter 2 – Electrified powertrain technologies as an alternative to regular combustion engines

This chapter provides a summary of the current role Electrified Vehicles (EV) have nowadays in road transportation, more specifically in European markets, and what the key factors are that will shape their adoption. Examining how the trends have evolved over the past years, as well as understanding the variables that have influenced its development, leads to better judgements on how the upcoming future will likely evolve.

I – Current progress of EV

Since the recent introduction of BEV in worldwide markets they have progressively gained popularity. In addition to PHEV and HEV, they represent the main alternatives to conventional combustion engine vehicles. The benefits of their significant degree of electrification helps them to attain better fuel efficiency than their homologous ICEV. It is the case also for HEV, even if they rely completely on fuel to be operational, they can still reach considerable reductions thanks to the electric motor and recovered energy from the regenerative braking. Because of their petroleum reliance, they most frequently are not assumed to be AFV [15] or completely electric vehicles. BEV and PHEV independence - or significantly reduced dependence of fossil fuels - is the main reason to support their adoption. That is why they are placed as a promising mobility alternative for the near future. But despite the increase in market penetration in their early growth stages, their current adoption rate is far from reaching the initially expected levels.

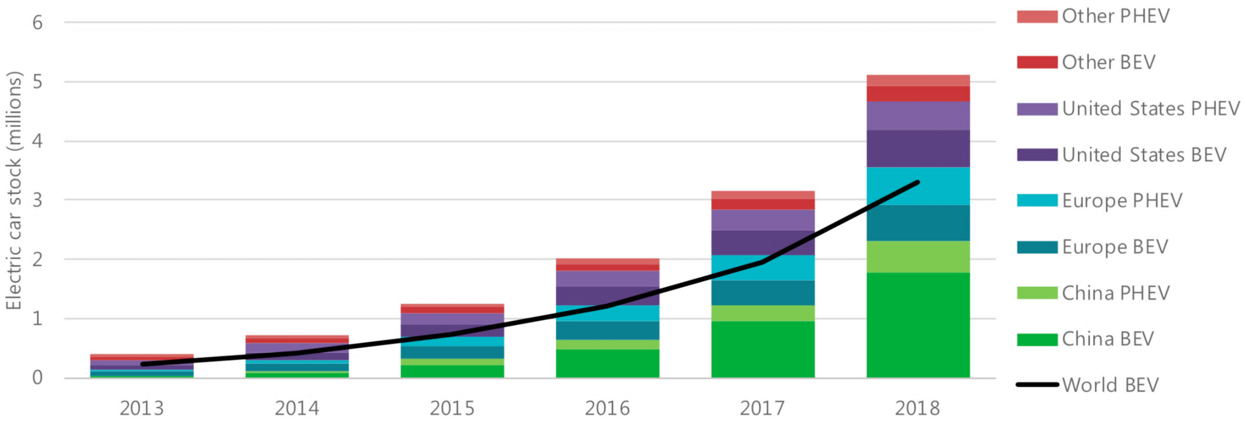

Figure 4: BEV and PHEV market penetration and in-use vehicles in major markets worldwide [16].

Global sales in BEV and PHEV increased significantly in 2018 with respect the year before. The amount of new electric-vehicle registrations doubled, reaching more than 2 million worldwide according to multiple sources [17] [18]. China remained the first market in number of sales, reporting for the first time more than a million EV sales, which almost doubled their electric vehicle stock. United States and Europe follow the lead in electrified powertrains adoption, accounting for 1,1 and 1,2 million of plug-in vehicles on the road respectively. Both market penetrations reached numbers close to 300.000 new registrations. However, numbers remain modest since global light-duty vehicle sales in 2018 were 94,8 million vehicles worldwide [19]. The electrified powertrains relevance is even more important for two and three wheelers vehicles, but this topic remains out of the scope of this research.

The yearly increase in sales that electric vehicles have experienced in this first five years of introduction in road transportation is remarkable. Through 2016 and 2017, the relative increase with respect to previous years was 60% and 56% respectively. Most recent data in 2018 describes a 63% increase in electric vehicle sales regarding the year before [20] [21]. Reaching an estimated stock of BEV and PHEV of 5,1 million in-use vehicles over the past year. Nevertheless, their part is yet quite modest in absolute terms. The average market share penetration is **2,1%** of global LDV new registrations. Generally, its place is yet far from being representative. Only a few countries have managed to challenge internal combustion engines predominance.

As the scope of this research is studying the future impact of electrified powertrains in European countries, a more detailed focus is given to the trends of six characteristic countries. These countries will also be the ones chosen to assess their EV adoption impacts and analyze the potential environmental benefits.

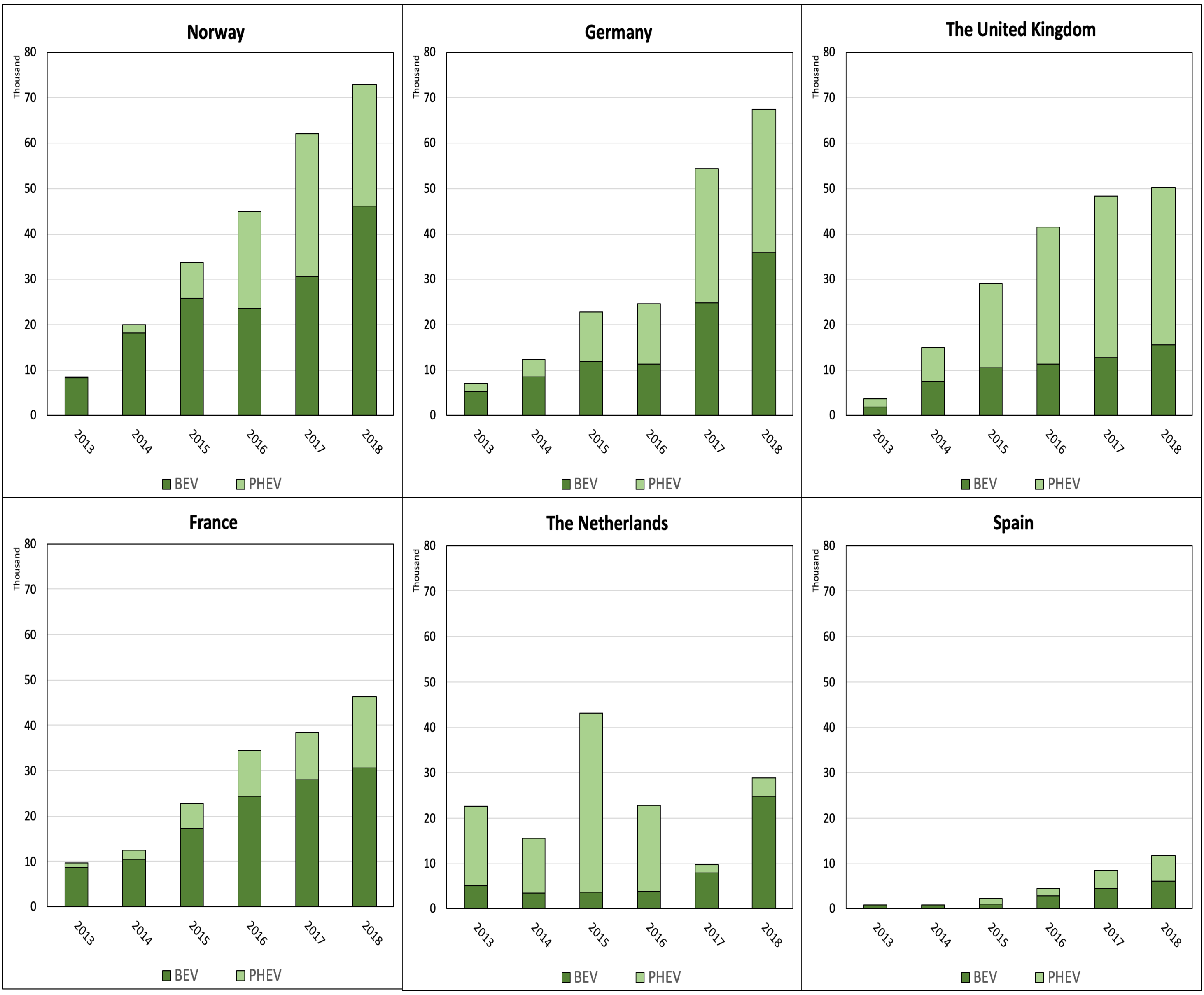

Figure 5: Total number of new PHEV and BEV registered in major European countries. Values in graph represent [20] [21].

The above figure summarizes the evolution over the previous years in the studied countries. A common pattern can be inferred over these countries, as the overall number of new registrations increases in all of them, the share of electrified powertrain becomes more relevant as well. Eventually the speed at which these greener technologies are being introduced varies from one another, identifying a clear country where EV have a significant higher rate of acceptance.

Norway

Norway as a leader in EV adoption guides the rest of the world in building what looks like a scenario with a high representation of electrified powertrains. Taking into account BEV only, the market share in 2018 was 31,2% of total new LDV registrations. If PHEV are included as well, the market share of AFV rises up to close of the half, 46% [22]. This trend of having more electrified powertrains is sustained over the first quarter of 2019, having a bigger impact on the total number of sales. For the first time reaching a historic 50% share of new vehicle registrations in a country.

Iceland and Sweden are the only countries well ahead in electrification of their LDV fleet: yet still far from the rates of adoption found in Norway. Their success is partly linked to the policies put into effect, as we will explore later.

The sum of BEV and PHEV in Norway is around 340.000 in-use vehicles, last updated on June 30th 2019 [23]. This constitutes about 10% of the total number of cars in that country. Moreover, Norway's government has set a time limit for ICEV as they plan to allow only all-electric vehicle sales by 2025 [24].

Germany

The next European country in number of LDV electrified vehicle sales is Germany. BEV market penetration reached 1% in 2018, with close to 36.000 all-electric vehicles sold during the past year [25]. If PHEVs are included as well, the amount of new registrations for electric vehicles rises up to almost 70.000 vehicles. This sets a promising starting for the upcoming development of EV in the broadest European car market. In a country where traditionally petroleum fuel vehicles have had an important representation, hosting some of the most renowned companies in the automotive industry, electric vehicles are starting to take firm steps towards a less fuel-fossil dependent transportation sector.

With 47 million vehicles on German roads according to latest KBA data, the representation of electrified powertrains is yet very modest. Roughly 140.000 BEV and PHEV are being daily used. This entails the capability, yet to be exploited, to develop a more sustainable mobility in the future.

United Kingdom

The deployment in its early stages of electrified powertrains in the UK confirms the sustained trend over the rest of European countries where the popularity of zero-emissions tailpipe powertrains is increasing. Being the second biggest market in Europe, it reaches the near figure of 60.000

electric vehicles sold. Attaining a non-negligible 2,7 % of the total sales, both BEV and PHEV are being successfully introduced into the British LDV market.

The vehicle stock evolved from 3.500 units in 2013, to more than 234.000 in-use LDV nowadays [26] [27].

France

France market is also not an anomaly in electrified powertrains adoption. It represents the second European country to achieve the 100.000 electrified powertrain registered LDV. These vehicles have been gaining popularity recently, leading them to come close to a 1,8% of market share. The total number of all-electric LDV sold in the preceding year was around 39.000 units [28]. Since the early 2000s, diesel fuel engines have ruled new vehicle registrations, mainly driven by French automakers which have particularly focused on developing this particular engine technology. Nevertheless, recent years show this is no longer the case as diesel vehicles have been negatively affected by regulations. This could potentially leave an opening for EV to expand faster. Also, the French government continues announcing the banning of ICEV sales by 2040 [29].

The current stock of BEVs and PHEVs on the road is close to 250.000 vehicles. It is the largest on road electric fleet in any European Union member.

Netherlands

The Netherlands is a country where electric vehicles have performed particularly well historically, specially PHEVs comprise for 81% of the share of AFV. Nonetheless, the EV trend seems to be changing towards BEV, which are gaining predominance. With a market share of 5,8%, it represents an advanced country regarding EV adoption. The barely 24.000 LDV registered in 2018 contribute building a solid base for the Dutch market to become an outstanding vehicle electrification pole [30].

Accounting for already more than 121.000 LDV registered plug-in electric vehicles, their share in the total fleet represents approximately 2,5%.

Spain

The electrification of the road transportation sector in Spain is making remarkable progress. Despite its early phase with a poor success, electric vehicle market penetration rates are gaining importance recently. They achieved a 0,9% of new registrations share, contemplating almost 12.000 plug-in LDV registered during 2018 [31]. However, BEV and PHEV have potential to overcome the 2% threshold over the actual year and current numbers account for that [32].

Having an estimated figure of 35.000 registered electric vehicles in the Spanish LDV car fleet, plug-in electric vehicles account for less than 1% of the in-use total.

II – Incentives as strategy to close the existing gap

No matter how interesting the electrification of LDV fleets might seem in terms of GHG emissions, there are other key factors involved when deciding to shift towards more fossil fuel independent vehicles. The convenience from a user perspective must be sufficient in order for large number of users to decide to adopt one of these greener technologies. Incentives from the governments and institutions are a key factor driving the change towards EV adoption. They are an effective strategy which reduces the difference between an ICEV or an AFV. At the same time, they support consumers in their decision-making process to purchase a more environmentally friendly vehicle.

In this section, a review is presented of the regulatory measures the European Union has implanted to reduce the adverse contributions to GHG emissions from the road transportation sector. More detailed analysis regarding the existing incentives to close the gap between electrified powertrains and ICEV in the six studied countries is carried out. This is necessary to understand up to what extent they can contribute in the adoption of electrified powertrains.

Development of a framework to set emissions reductions goals

Policies are conceived to enhance the accomplishment of stated, achievable goals. Therefore, it is important to learn what is their ultimate intention. In the line of a generalized change to more sustainable less carbon-dependent economy, the European Commission decided to adopt a specific low-emissions mobility strategy in 2016. This road map towards a more environmentally friendly road transportation sector is set in order to **attain in 2030 a 40% reduction with regard to 2008** levels. Having a broader horizon, it represents an 80-95% reduction in 2050 related to 1990 GHG emissions. Both reduction steps are aligned with the Paris Agreement of limiting the global warming to 2ºC by 2050. The targets are initially stated in the “White Paper on Transportation” [33], and reiterated at the 2030 EU Climate and Energy policy framework [34]. Both documents gather an extensive analysis on the factors influencing the deployment of the transportation sector. It is in this frame of work that more specific policies at different European levels have been built [35].

Since Light-Duty Vehicles are responsible for 15% of total European GHG emissions, it is crucial to restrict their contribution. The growing pace of road transportation in total share has pushed policy-making authorities to encourage the CO2 emissions reduction in new vehicles. As most of new vehicle registrations still rely on petroleum fuels, mitigating their contribution by improving fuel-economy is an important strategy to face the upcoming years ahead. Whereas AFV deployment without other reinforcing measures is unlikely to change this trend rapidly. Previous policy had targeted levels for new cars in 2015 of **130 gCO2eq/km**. In case the average fleet emissions of a given manufacturer surpasses the standing legislation's target, an excess emissions premium has to be paid by the manufacturer for each registered car. This fee accounts per every gCO2eq/km in excess. The response from the automotive industry was surprisingly positive by mostly reaching these levels two years ahead in 2013. Light-commercial vehicles (LCV), also commonly known as vans, were scoped by European legislation in 2011, two years after cars, with **175 gCO2eq/km** as objective. Their response was even more significant reaching the targeted levels in 2013, 4 years in advance of the fixed timeline. Greenhouse Gas emissions per km have been going down since 2010, reaching in 2018 barely **120 gCO2eq/km** and **158 gCO2eq/km** for new registered cars and vans respectively [36] [37].

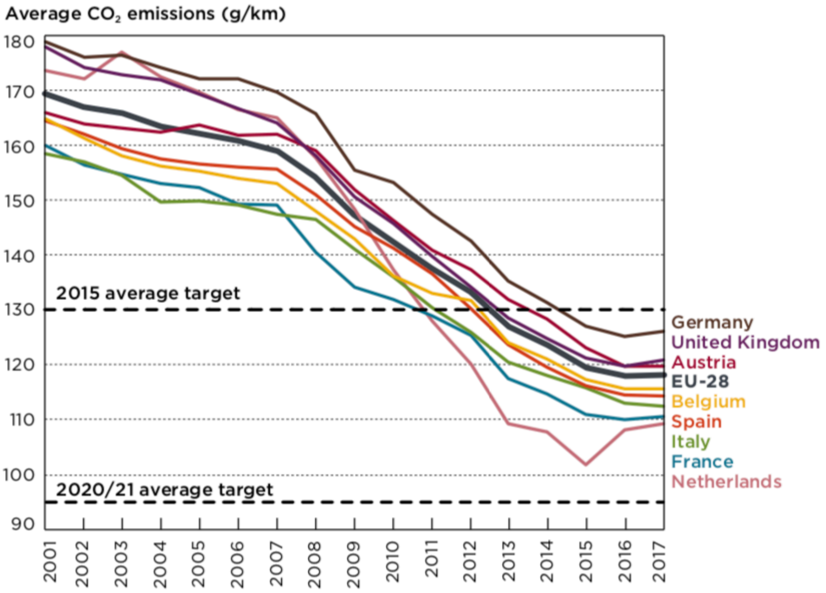

Figure 6: Passenger car average new registrations emission evolution by European country [38].

As Figure 6 shows, since the announcement from the European parliament on the approval for legislating new LDV registrations in 2007 [39], the average emissions per kilometer have followed a steeper downward trend. This underlines the effectiveness of such policies which have brought a reduction of **20 gCO2eq/km** since 2010. Extended to all the new registrations of passenger cars in the European Union it shows the consequent benefits in terms of GHG emissions. As a matter of facts, the strong link between vehicle tailpipe emissions and its fuel-efficiency indicates a major decrease in passenger cars fuel consumption. This helps to mitigate the foreseen increase in oil prices, maintaining vehicles operating costs or even in some cases reducing them. Nevertheless, recent data raises a different tendency where the pace of average emissions reduction has been slowed down or even increased in some of the countries.

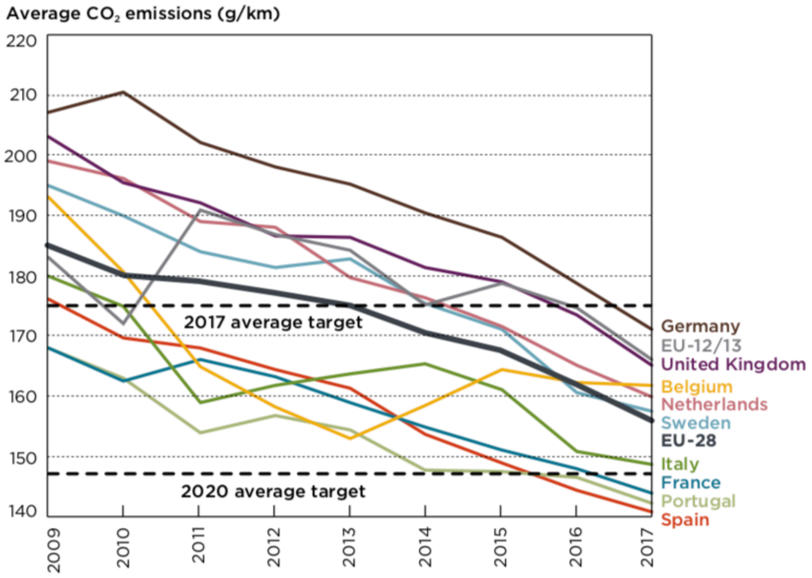

Figure 7: Light-Commercial Vehicles new registrations emission evolution by European country [40].

The reductions regarding European countries van fleet's exhibit a similar pattern to cars. With a progressive decrease in the amount of CO2 per km over the preceding years, some countries such as France, Portugal or Spain have attained the 2020 average emissions target four years earlier.

Electrified powertrain vehicles and its adoption are also promoted by these emission regulatory policies. As the average emissions are calculated taking into account the manufacturer's vehicle models sold, having more success in selling AFV will give a better margin in achieving the objectives and compensate those models which GHG emissions are higher than the standards. On top of that, the Super Credits or ZLEV incentives will make the participation of vehicles below 50 gCO2eq/km more significant, by applying to them higher weight factors while calculating the average fleet emissions.

Incentives dedicated to enhance EV adoption

Aligned with European Commission guidelines towards a more sustainable road Transportation sector, governmental institutions have established certain regulatory policies to lead the way for AFV adoption. These measures aim specifically to increase the purchase incentives and convenience of using more environmentally friendly powertrain technologies in the countries where they apply.

The following table summarizes the utilization of existing types of incentives and how they are adopted across the full European territory. It indicates about the degree of implication government's incentives have regarding electrified powertrain introduction.

Table 1: Summary of the current EV incentives in European countries [41] [42].

Country	Purchase Subsidies	Tax Benefits	Business Benefits	Infrastructure Incentives	Local Incentives
AUSTRIA	✓	✓	✓		✓
BELGIUM	✓	✓	✓		
BULGARIA	✓				
CROATIA	✓	✓			
CYPRUS		✓			
CZECH REPUBLIC		✓			
DENMARK	✓	✓	✓	✓	✓
ESTONIA					
FINLAND	✓	✓			
FRANCE	✓	✓	✓	✓	✓
GERMANY	✓	✓	✓	✓	✓
GREECE		✓			
HUNGARY		✓	✓		✓
ICELAND	✓	✓		✓	✓
IRELAND	✓	✓	✓	✓	✓

ITALY	✓	✓		✓	
LATVIA		✓			✓
LITHUANIA		✓			✓
LUXEMBOURG	✓	✓	✓		
MALTA	✓	✓	✓	✓	✓
NETHERLANDS		✓	✓	✓	
NORWAY		✓	✓	✓	✓
POLAND					
PORTUGAL	✓	✓	✓		✓
ROMANIA	✓	✓		✓	
SLOVAKIA	✓	✓			✓
SLOVENIA	✓	✓			
SPAIN	✓	✓	✓	✓	✓
SWEDEN	✓	✓	✓	✓	✓
SWITZERLAND		✓			
UNITED KINGDOM	✓	✓	✓	✓	✓

Most EU members have adopted complementary policies to enhance the European Commission legislation. Incentives are considered effective if they enhance the probability of consumers to buying an AFV. They intervene directly in the decision-making process of consumers who are contemplating renewing their personal transportation vehicle. The push policies are crucial, as they promote the development from the side of the automotive industry which pull into the market with more attractive models. Otherwise the introduction of electric vehicles in LDV sales would be limited by the barriers to adoption: in other words, it would be much harder to overcome the initial constraints.

A more detailed approach is needed to understand the effectiveness of these incentives. Going further, an analysis is carried out that addresses the six major European countries studied in this work. The goal is to describe the precise measures in these markets and how sales have been affected after their implementation.

Purchase subsidies

In an effort from public administrations to promote EVs purchases, a specific amount of the regular market price of less GHG emitting vehicles is deducted. Known as purchase subsidies, they provide financial support to those customers who decide to buy an AFV. Generally, this is a direct reduction of the retail price. The amounts may differ, depending on the country and the emissions per kilometer certified in tests. The following table summarizes the purchase subsidies for the major six European countries studied in this thesis.

Table 2: Purchase subsidies for LDV new registrations from countries studied and effective period [41] [42].

Country	BEV Purchase subsidies	PHEV Purchase subsidies
NORWAY	-	-
GERMANY	• 4000 € when vehicle price below 60.000 € (2016-2019 or 400.000 sales) [43]	• 3000 € when vehicle price below 60.000 € (2016-2019 or 400.000 sales)
UNITED KINGDOM	• Cars 35% of purchase price, up to 3.500 £ • Vans 20% of purchase price, up to 8.000 £ (2011-2020) [44]	• Cars 35% of purchase price, up to 3.500 £ • Vans 20% of purchase price, up to 8.000 £ (2011-2018)
FRANCE	• Bonus up to 6.000€ in purchase discount for vehicles emitting under 20gCO2eq or 27% of the acquisition cost [45] • Additional bonus for older vehicle scrappages, up to 5.000€ (2012-)	• Bonus up to 6.000€ in purchase discount for vehicles emitting under 20gCO2eq or 27% of the acquisition cost (2012-2018) • Additional bonus for older vehicle scrappages, up to 5.000€ (2012-)
NETHERLANDS	-	-
SPAIN	• Cars Up to 5.500 € when purchase price below 48.400€ • Vans Up to 6.000 € when purchase price below 48.400€ (2011-)	• Cars Up to 5.500 € subject vehicle range when purchase price below 48.400€ • Vans Up to 6.000 € subject vehicle range when purchase price below 48.400€ (2011-)

** Some of the purchase incentives amounts may have differed over time while they were in place.*

Tax Benefits

The most common tax benefit is a significant - or even total - exemption on their Value Added Taxes (VAT). It usually is compensated by a rise on regular combustion engine vehicle's taxes, especially of those not complying with the environmental legislations.

Some countries like Spain also release BEV from their registration tax. In France the percentage depends on the region, whereas in UK it applies depending if the BEV purchase value vehicle emissions, is less than 40.000 £. In the case of Netherlands, the registration tax is calculated as a function of the gC02eq/km, when the vehicle is certified.

Another form of tax benefit is road tax exemption. This is the tax needed to allow vehicles on the road. For most of the studied countries, this circulation tax is removed or broadly reduced for greener powertrains.

Norway deserves special mention: there the tax benefits are a key component in explaining the great success electrified vehicles have experienced. Incentives for low-emissions powertrains started to be adopted in the early 1990s. The Norwegian government does not give any financial support based on the purchase of the vehicle itself. Their efforts converge on having a taxation system that benefits buying an electric vehicle. With a 25% VAT and road circulation tax exemptions, and no registration or import tax applied to all EVs, strong conditions that encourage AFV adoption sat up. The sum of all these incentives makes EV an attractive option as a daily means of transport. In the Norwegian LDV when comparing total prices of the same vehicle model but with different powertrain versions, the electrified version usually has a lower price [46] [47].

Business Benefits

Similar to tax benefits, they target directly the EV adoption among corporate vehicle fleets. These allows to reduce company taxes while using electrified powertrains for professional purposes. Particularly, in Germany the use of BEVs as professional vehicles is treated as taxable income for the company at a fixed amount of 1% of the purchase price.

Infrastructure Incentives

Infrastructure development is considered as a key asset to succeed in the AFV adoption. As new powertrain technologies rely on other refueling / recharging methods, different from the conventional refueling process, a new network to assure the availability of adequate energy supply has to be developed. Therefore, several incentives aim to ease building new charging points.

One of the strategies to promote the adoption of plug-in vehicles is to promote installation of rechargers in private households by offering grants. In UK eligible customers may receive up to 75% of the costs of installing a charging point, limited to 500 £. French homes can benefit from a 30% tax credit for installing a residential charging point.

Other countries such as Norway and Germany have approved a budget to develop a more functional charging station network, setting target numbers as goals. Spain follows the same trend by having funds destined to promote the development of the public and private charging points.

Also, in countries like in Netherlands, it is possible to deduct the amount invested in developing clean technologies from corporate or income taxes. This applies while developing the recharging infrastructure by installing new charging points at households or workplaces.

Local incentives

Regarding local incentives they are intend to support the increase in convenience of low-emissions vehicles by allowing users to drive in special lanes, having free parking in given locations or granting access to user to congested city centers. Especially these local measures promote behavioral changes in drivers, as they aim to reduce cities air pollution and congestion. They also infer priority to public transport and more sustainable mobility solutions, which are viewed as more advantageous.

Partial conclusions

Each of the existing types of incentives has a complementary effect. Their cumulative impact closes the gap between new powertrain technologies in its early stages of adoption and conventional ones. It can be observed that sales increased considerably by the time incentives came into effect. The market penetrations of plug-in electric vehicles are strongly influenced with the presence of incentives in its early stages of deployment. They surely represent an effective tool to rise the number of EVs on the road.

However, other important factors such as automakers' efforts to design and produce more attractive car models for consumers and the economic situation in each individual market are also important for understanding the success of AFV. In order to be able to analyze the effectiveness of incentives exclusively, it is necessary to frame each situation. To correlate the deployment of incentives with their direct impact in market shares and evaluate their relevance, more variables need to be understood. This would need a supplementary analysis for each country studied, which is out of the scope of this thesis. Nonetheless, the information gathered in this thesis is sufficient to understand that incentives play a key role for guiding the path for electrified powertrains.

This gives an overall idea of the existing tools in European countries that drive the change. Electrified powertrains have managed to close the gap thank to the in-effect incentives partially, and the proof is that EV sales volumes have experience a generalized increase since their approval. The market penetration of electrified powertrains has gained relevance and actual trends confirm an even brighter future. Analyzing if without these incentives the adoption would continue is out of the scope of this research, but analyzing the effects would estimate the real progress these technologies have done during the past years.

III – Present and Future Barriers of adoption of AFV

However surprising the AFV market penetration evolution has been in the previous years, still many challenges remain uncertain regarding their immediate future development. Differentiation must be done between the introduction of these technologies and their large-scale adoption as an effective solution to replace on a daily basis current road transportation means. As it has been explained in the precedent section, incentives are an effective strategy to encourage the adoption of new mobility options to users. Nevertheless, in some aspects current incentives have little capability to enhance electrified powertrains. More social and technological strategic factors must be developed to assure the extensive use of these types of vehicles.

Discussions over the main current, and then future barriers of adoption are carried out through this section. Awareness on the challenges of introducing these greener powertrains is the first step to successfully overcome their limitations.

Battery technology limitations

Thanks to recent improvements in battery technologies, it has been feasible to introduce rechargeable vehicles into the market. Guided by HEV models that previously have served as pioneers for adopting larger batteries than regular ICEV, new electrified powertrains have been conceived increasing considerably the energy density of their batteries, hence having higher energy storage capacity. Nowadays, BEV commercial models benefit from batteries up to 100 kWh. Therefore, their high energy density, high power density or low rates of self-discharge represent strengths that enhance their deployment. However, the use of batteries as energy storage systems implies many other challenges to EV adoption.

The cost aspect is a key factor when deciding which type of powertrain should be adopted. Electrified powertrains have higher purchase prices compared to conventional combustion engine vehicles due to the cost that have higher battery systems.

It is true that in recent years the gap between these vehicles' cost has been reduce. Thanks to important investments in building bigger factories and better knowledge in battery manufacturing techniques, it has been possible to scale down costs. Uncertainty, especially in expensive battery materials amount and their stock evolutions, makes it hard to predict future costs per kWh of battery storage capacity with confidence. Nonetheless, the average prices have been going down by a 14% annually between 2007 and 2014 [48]. Starting at the beginning of that period with costs above 1.000 $ / kWh, they nowadays approach 176 $ / kWh when it comes to battery packs for electric vehicles applications. Price reductions in the last years represent the promising progress battery technology is making, but this progression has slowed down below an average 8% yearly decrease [49].

Nonetheless, in situations when incentives are not considered, retail prices remain significantly higher than ICEV with similar characteristics. The experienced evolution curve itself is unlikely to attain the necessary levels to make electric mobility more attractive than internal combustion engines in the near future. In absence of incentives, the even price between battery electric vehicles and conventional vehicles is considered to be 100 $ / kWh, which is been proved to be difficult to reach it at least for the next ten years. Therefore, structural innovations on the storage technology itself and the materials used will likely be needed in order to achieve levels where BEV become cost competitive, independently of the incentives in place [50].

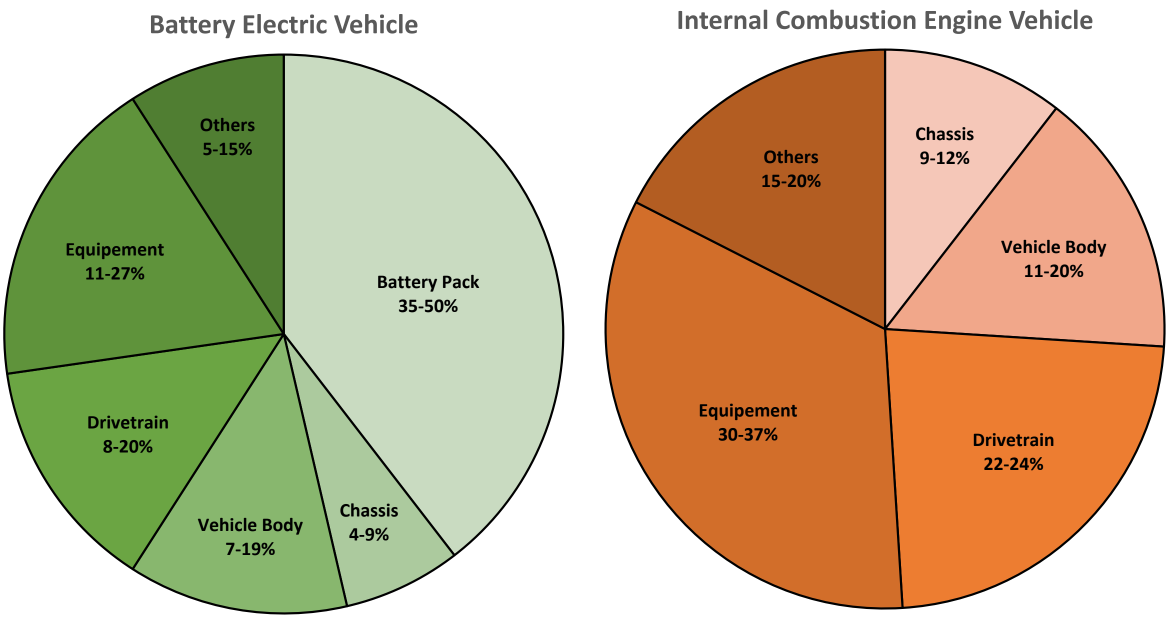

Figure 8: Total costs breakdown comparison between Battery Electric Vehicles and Internal Combustion Engines. Percentage intervals indicate the variability of each of the components in the total share costs [51].

The weight of the battery cells in electric vehicles represents an important percentage of its total. Currently it represents around 250 kg for an average compact BEV model and increases up to 450 kg for big pick-up electric vehicles [52]. As the battery capacity is linked to the travel distance per recharge that an electric vehicle has, extending its range does not only increase its price considerably, but it also affects the performance of the vehicle. Although trends show more compact batteries in the future in order to reduce their weight considerably,

Last but not least, the useful life of current battery technologies makes electric vehicle adoption more challenging. Battery performance is notably influenced by electrical, mechanical or thermal factors. The effect of battery aging is linked to the number of recharging cycles and under which conditions they undergo [53]. Estimating more accurately the aging mechanisms of batteries is crucial for determining their total useful remaining life. It determines how the total emissions as a consequence of the battery manufacturing process would be shared over the full vehicle's life.

Recharging process and network

At first sight, one of the most striking differences between plug-in electrified vehicles and combustion engine vehicles is how they procure the energy for their propulsion systems. Even the word describing the action differs. While the first type of vehicle needs to be connected to an energy source – generally the grid – to recharge, the other can refuel its tank at any gas station. Currently there is a wide variety of recharging options for plug-in vehicles. They are usually classified by maximum charging rates (in kW) and leverage the ubiquitous electrical grid, respecting its connection requirements. The following table summarizes all the available charging levels in the market, with 22 kW of power being stablished as the boundary between slow and fast chargers.

Table 3: Current methods available for EV recharging [54] [55].

Attributes	Level 1	Level 2	Level 3	Level 4
Description	Slow charger Conventional household plug	Slow charger Public charging point	Fast Charger Still in Alternate Current (AC)	Fast Charger Direct Current (DC) conversion made
Nominal Voltage	AC 1 Phase 250 V 3 Phase 480 V	AC 1 Phase 250 V 3 Phase 480 V	AC 1 Phase 250 V 3 Phase 480 V	DC 600 V
Maximum Current	16 A	32 A	32 A	400 A
Power	< 3,7 kW	≥ 3,7 and ≤ 22 kW	> 22 kW and ≤ 43,5 kW	≤ 400 kW

In contrast to the current petroleum-based fuel refueling network which is well spread, the availability of recharging points is less obvious. In order to promote the development of a more accessible charging network, European countries have to set targets for its deployment and forecasted the number of EV sales. The European Commission suggests to have at least one public charging point (PCP) for each ten electric vehicles for 2020. After analyzing recent results, the goals are likely to be met in following years [56] [57]. However, it has been realized at its early stages that public charging points are not being used as much as expected.

After the early stages of adoption have been successfully realized, an important problem arises. The continuation of the development of the recharging network requires a considerable investment. This linked to still modest market penetrations of EVs and to existing recharging techniques far from being as convenient as refueling in most of the situations, makes it less attractive for investors to finance the complete build-out of the network. Big progress has been made in most of the European major countries, where plug-in vehicle adoption still at its early stages is gaining relevance, communicating optimism for future development. Incentives are expected to become a key factor in building the cornerstone of a much broader and effective recharging network.

Nevertheless, the recharging process entails a much more relevant limitation from a consumer perspective. Recharging times are far from being as competitive as pumping fossil fuels to fill regular combustion engine vehicles' tanks. In a typical best-case scenario, a fast charger could offer an 80% complete charge of the battery in around 20 minutes, depending on the ambient conditions. Also, how the battery aging is going to be influenced by these state-of-the-are recharging techniques is yet to be studied in more detail.

Automakers’ efforts to change consumers perception

Traditionally most of the current automakers have developed exclusively internal combustion engines vehicles. The change towards electrified powertrains entails reshaping progressively their current business model. Therefore, the plug-in vehicle technology requires significant resources, not only for continuing making progress towards more robust powertrains, but also in changing consumers’ state of mind. It is in that particular aspect that automotive manufacturers have not been that successful. Promoting new powertrain technology vehicles has a direct impact on the willingness of consumers to buy them. However, recent studies show that car manufacturers aim to promote larger vehicle segments, rather than shifting towards more electrified powertrain [59]. Although, the budgets accounted have increased in the previous years, aiming ambitious sales goals from the side of car manufacturers [59].

Energy demand increase

The load electric vehicles could significantly affect the electricity grid’s future, its energy demand and its distribution through the day. In order to be capable of efficiently manage the new loads that EV adoption implies, the development of what is commonly known as smart grid is advisable. This would be necessary in order to avoid the instabilities that larger fleet penetrations of plug-in vehicles would entail. For instance, to recharge a single electric vehicle with 24 kWh of battery capacity, it would be required the same amount of energy than for a European household per day. Also, in case of installing a private charger, it would increase its current demand by 17% to 25% [60]. The aggregate effect would imply important loads in peak hours, leading to load unbalance and degradation of power quality. However, a broader assessment on the energetic profile, economical aspects and operational impacts is needed to give more clearance each specific case. In other words, for a successful adoption of electric vehicles, the electricity grid should evolve and adapt in parallel.

IV – Relevance of electricity supply and vehicle production

When assuring that AFV will become a more environmentally respectful solution, some factors need to be considered with caution. In spite of not having tailpipe emissions – or less significantly in the case of PHEV – electric vehicles do consume electricity, which at the same time is supplied by the grid and produced from different energy sources. These energy sources are always associated with certain amounts of emissions. Analyzing the electricity generation process with Life Cycle Assessment (LCA) data is important to consider the GHG emissions associated with the overall process. This gives a more comprehensive knowledge about the actual benefits of adopting alternative powertrain technologies. Though it is a complicated task to gather all the relevant information to specifically assess life-cycle GHG emissions at each scenario, using average values estimates conveniently each situation. The ultimate goal is to enable more reliable judgement while analyzing the trade-offs of introducing new powertrain technologies.

LCA methodology

When implementing a Life Cycle Assessment approach all different stages in the full life of the evaluated subject must be considered. Often described as a “cradle-to-grave” vision, it takes into account from the extraction of the necessary materials used in the process, until its end of useful life. Also, LCA includes all actions needed to dismantle and recycle the remains after the studied item is decided to no longer be suitable for operating. In order to picture the complete scene with accuracy, it leverages information from very broad sources. Therefore, to integrate all the interdisciplinary knowledge it requires to enlarge the understanding about the subject analyzed.

Therefore, LCA results a very accurate methodology to measure the cumulative environmental impacts. Contemplating all the factors involved helps to analyze all the outcomes of a given process, estimating the repercussion each of them individually have. Before performing any LCA, some aspects should be clarified.

The first thing is to define the scope and the goal of the assessment. Before conducting any evaluation, it should be defined what are the boundaries of the analysis performed and what is the final objective. Setting the boundaries may have a high influence in the results, that is why it exists an important variability between LCA from similar nature. Once all the limitation to the assessment are set, it is necessary to elaborate the inventory with all related processes. Identifying the nature of all the inputs and outputs to the LCA performed, as well as quantifying their environmental impact. For instance, all results should be ultimately measured in gCO2eq for the evaluating global warming effects. Every input data used for the analysis has to be contrasted and verified as far as possible, to guarantee complete and reliable outcomes. Principal frameworks for LCA are defined by ISO 14040:2006 [61].

Emissions LCA applied to energy generation sources

LCA data is also applied for electricity production. Although renewable energies represent a clear alternative for reducing GHG emissions related with the electricity production process, they are still linked to certain environmental impact. In this thesis, Life Cycle assessment data considers in each calculation all energy sources involved for supplying the required energy to recharge all the in-use plug-in electric vehicles.

The following table presents an example of LCA scope when performing GHG emissions calculations are conducted in two different energy sources. Percentage represent the share of emissions accounted at each stage of their useful life.

Table 4: Life Cycle Assessment comparison between Wind and Coal electricity production sources. Review of the actions considered and the percentage each stage represents in the total useful life GHG emissions.

Life Cycle Stages		**Wind**	**Coal**
Implementation processes	Actions considered	• Raw materials extraction • Module manufacture • Wind turbine and farm construction	• Raw materials extraction • Construction materials manufacture • Powerplant construction
	% of life-cycle emissions	~86%	<1%
Operational processes	Actions considered	• Power Generation • Plant Operation and maintenance	• Coal mining • Coal preparation • Coal transportation • Coal combustion • Powerplant operation and maintenance
	% of life-cycle emissions	~9%	>98%
Dismantlement processes	Actions considered	• Wind turbine and farm decommissioning	• Power plant decommissioning • Waste disposal • Coal mining land rehabilitation
	% of life-cycle emissions	~9%	<1%

But the energy generation process is not the only external factor that could potentially affect the emissions comparison between AFV and ICEV. As the components are different between each powertrain technology, the energy required to manufacture each type varies. In particular, battery manufacturing process are high energy intensive, introducing significant differences.

Emissions LCA applied to vehicle production process

When it comes to vehicle production process, remarkable differences exist between each type of powertrain. All the necessary components to constitute an operational vehicle are considered while performing a GHG emissions LCA.

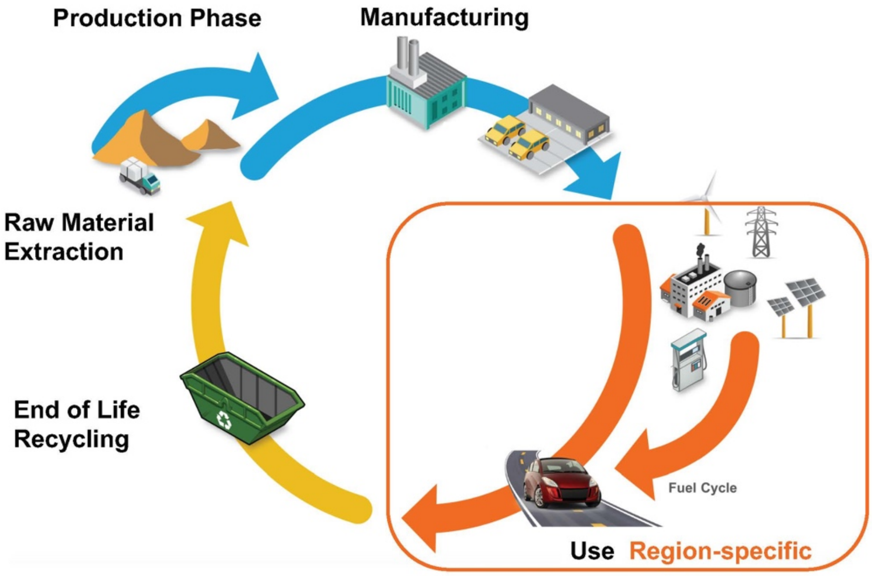

Figure 9: LCA stages in GHG emissions calculations over vehicle useful life [62].

The precedent figure illustrates the different stages considered while calculating the useful life GHG emissions of a regular passenger vehicle. Regarding the manufacturing process emissions, several assumptions rule the calculations. Depending on the useful life of the vehicle and the total distance travelled, the emissions per unit length would be separated differently. Also, the size and the technology employed for the powertrain influence the vehicle production outcome.

Notably, a higher uncertainty raises from the battery manufacturing process for electric vehicles. In the literature many studies can be found regarding this topic, with values going from 56 up to 250 kilograms of CO2eq per kWh of battery capacity [63]. Therefore, depending on the size of the and the materials employed for their manufacturing process, the total emissions could differ significantly.

To summarize, after considering all the important factors which have a relevant role while quantifying the total vehicle emissions, in average BEVs have the potential to reduce by a factor of two total vehicle life-cycle emissions. This is based on results of several related studies that take into consideration approaches on the same line than this thesis.

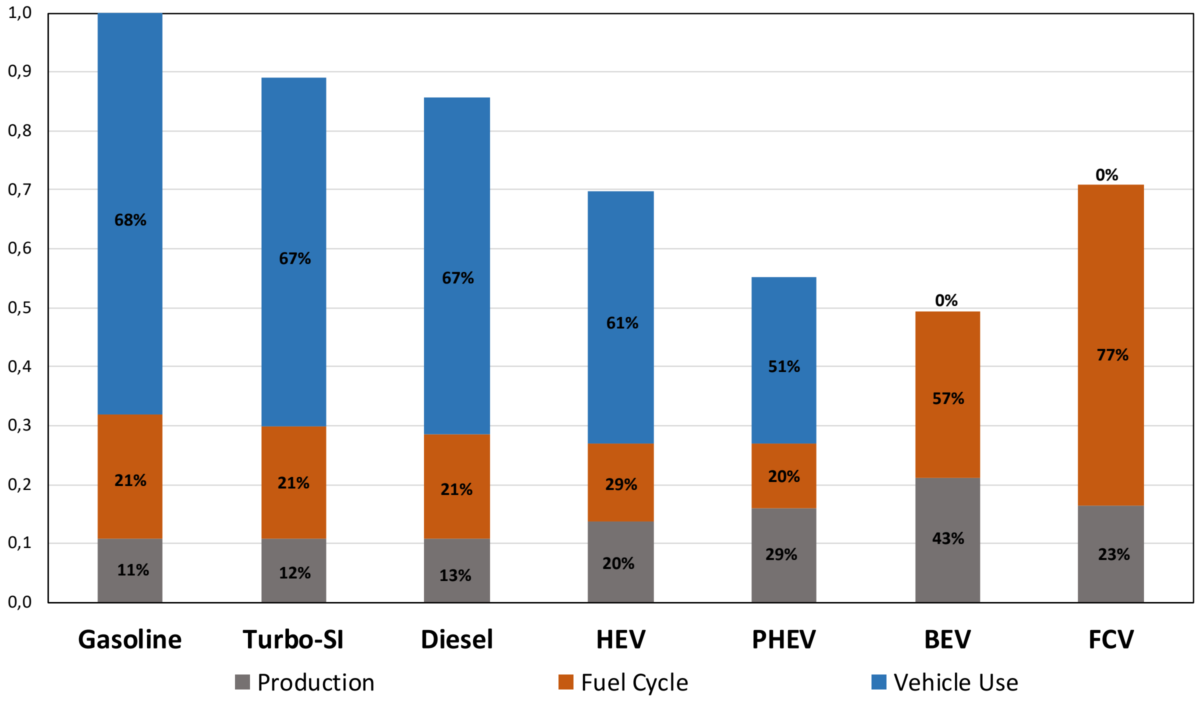

Figure 10: LCA GHG emissions comparison between different powertrain technologies available and their relative percentages for each life cycle stage [64] [65] [66].

Results shown in figure 9 shows benefits in terms of GHG emissions while assessing each available type of vehicle with LCA methodology. These results rely under various assumptions and represent a general idea of comparing the overall environmental impact of the powertrain technologies studied in this research. For instance, PHEV vehicle use and fuel cycle emissions rely on the percentage of kilometers travelled using electricity. Also, fuel cycle emissions of BEVs are directly related to grid energy sources, which may differ significantly from one region to another. Many uncertainties raise when calculating the fuel cycle emissions for FCVs, as hydrogen production for transportation uses is still on its early stages of deployment. However, the previous figure helps to understand in average the potential benefits of adopting greener powertrain technologies.

Chapter 3 - Strategies to reduce the carbon footprint from LDV fleets

Here are reviewed the existing strategies being used by major stakeholders to reduce greenhouse gas emissions from the road transportation sector. These strategies are usually based on a set of interrelated actions, and their effectiveness relies on the commitment of each party involved. They can be categorized based on the nature of the changes targeted. It is their overall effect that determines the total GHG emissions reduction. In this chapter, the most important strategies to reduce carbon footprint from LDV fleets in European countries are presented.

I – Vehicle improvement strategies

Improving vehicle emissions implies enhancing already existing powertrains and developing more fuel-efficient ones. Therefore, technology strategies that gather together all actions that contribute to better fuel economy from conventional vehicle technology are important. Emphasizing fuel consumption reductions requires a willingness to allocate current resources towards developing more environmentally respectful mainstream vehicles.

Better engine efficiency

Higher engine efficiency is achieved by applying technological improvements to upcoming vehicle models. The increasing adoption of turbocharged gasoline combustion engines provides benefits in the fuel economy of existing propulsion systems of up to 12%. Wider benefits are attained by adding a battery pack and electric motor, shifting towards a hybrid electric vehicle. This allows to reach an average 30% fuel consumption reduction. Other particular aspects for current engines, where improvement margin still is possible, are expanding the implementation of start / stop systems when idling the engine, increasing the operating compression ratios, or reducing the friction between mechanical components [67].

Vehicle weight reduction

When it comes to vehicle fuel consumption, vehicle weight has a significant impact. The mass of the vehicle directly affects tire rolling and acceleration resistances that oppose to motion. The vehicle’s inertial resistance also represents an important part of the load that the propulsion system needs to be able to overcome. Thus, reducing the vehicle’s weight lowers the total energy spent to produce its movement. Hence, shifting towards more lightweight vehicles represents an effective strategy in reducing their fuel consumption. As some studies have analyzed, obtaining a 10% weight decrease results in an average 7% improvement in fuel-economy, at constant acceleration performance [68]. The potential paths for successfully minimizing a vehicle’s weight are introducing lighter materials in the manufacturing process, reducing the size of the vehicles or redesigning some components in order to have more compact structures.

Tire rolling resistance and aerodynamic drag

Rolling resistances are not only dependent on the weight of the vehicle. The tire’s road contact surfaces, the materials used and their inflation pressure influence the friction coefficients, thus having an impact on the vehicle’s fuel consumption. This tire rolling resistance has experienced about 1% decrease year to year [69].

Aerodynamic drag is defined as the force that opposes vehicle’s motion through its surrounding air. It is proportional to the square of vehicle’s speed and therefore, most relevant when travelling at high speeds. Strategies for improving fuel economy by modifying the aerodynamic drag aim to reduce both the vehicles effective frontal area and its drag coefficient. This has a smaller potential for improving fuel consumption than targeting reductions in weight, but still represents an opportunity to develop more environmentally respectful vehicles.

II – Behavioral changes

Behavioral changes can also produce vehicle environmental benefits. These could come from more responsible use of the existing means of transportation.

Reduction in vehicle kilometers travelled

Travelling daily remains a hard-to-avoid need. However, responsible use of the means of transport available should be the personal responsibility of all citizens. By enhancing public transport networks and other complementary means of transportation to replace conventional passenger cars in an effective way would provide environmental benefits. The direct implications could reduce the number of Vehicles Kilometers Travelled (VKT) significantly, and the GHG emissions associated with road transportation. This trend has been well adopted in major European cities, but further progress is possible for reducing traffic congestion due to extensive vehicle use.

Less aggressive driving behaviors

Use of more respectful driving patterns can also reduce LDV emissions. While avoiding unnecessary accelerations and braking cycles, and too high speeds, the overall fuel efficiency improves. It is the main cause to why vehicle test cycles have lower fuel-consumptions values than real life on-road performance. The average gap between tested cycle emissions and real world corresponds a 20% reduction for WLTP cycles. This may also differ between the test-cycle used to determine fuel consumption [70].

Benefits from fleet turnover towards more fuel-efficient vehicles

Encouraging the turnover of vehicles in the fleet turns out to have important benefits in terms of GHG emissions. More vehicles with better fuel-efficiencies are introduced into the market, their potential to mitigate environmental impact increases. In other words, as years pass the positive emissions impact of replacing old vehicles with higher fuel consumptions becomes more relevant. That is why, by motivating consumers to renew their personal vehicle more often, the average emissions of the in-use car parc are decreased.

III – Strategies aiming for transformation

Strategies aiming to transform powertrain and vehicle technology to more energy efficient ones represents a clear path towards significant reductions in GHG emissions from the transportation sector. However, this has to be considered as a medium- and long-term strategy, as well-advanced transformation is necessary to achieve remarkable effects.

Introduction of greener powertrain technologies

Promoting the adoption of greener powertrain technologies is often viewed as the most effective solution to reduce LDV emissions. Plug-in electric vehicles rely on electricity generation to reach their emissions benefits with respect to conventional engines. Although for all countries studied in this thesis, which have an important contribution of electricity generation from renewable sources, this is proving an effective solution to mitigate road transportation emissions.

However, to change towards these new greener powertrain technologies their initial barriers to adoption have to be overcome. The consumers perspective, motivated by incentives, will determine the AFV adoption rates. As it is explained in Chapter 2, even if the levels of market penetration of these technologies are already relevant, they are still in its early phases for most of the European countries.

Another effect of adopting AFVs in major European countries in-use fleets, is the potential displacement of the vehicles' distance travelled. As some studies have shown previously, plug-in electric vehicles are less driven than conventional ICEVs [71]. This raises the question whether introducing AFVs displaces the distance travelled by the total fleet, or indeed it will require a higher number of vehicles to offer the same mobility requirements. Nevertheless, this remains out of the scope of this thesis work and in terms of vehicles travels, all are considered the same.

More sustainable energy supply

Transforming strategies also requires improving the existing electricity grid. Replacing energy supply sources with more environmentally respectful ones has an immediate impact on the total LDV emissions. As the market share of rechargeable vehicles increases, the load they represent in the electricity supply becomes more important. This increases the relevance of having a greener grid, which will account for the emissions of generating and transmitting the required amount of energy. Nonetheless, reducing the average carbon intensity from the grid only has relevance, in terms of road transportation emission, when BEV and PHEV reach a significant percentage in the in-use vehicle fleet.

Chapter 4 - Fleet Model Simulation Tool

The use of a simulation tool is the cornerstone of this thesis for analyzing the impact of introducing on the road newer powertrain technologies. Yet predicting the consequences of forecasted scenarios implies a degree of uncertainty among the results obtained, it serves as a quantifiable source of information for comparing the relative impact of different rates of adoption. In this chapter the reader can find a detailed description of the simulation model developed for this research and how it has been conceived.

I – Description and advantages of Fleet Model

First of all, it is important to clarify notions used while describing the model. The timeline horizon is defined as the final year of simulation, for all cases it will be 2050. At the same time, the starting point which all future results will be based on is 2017. Data is used for all previous years calculations, beginning the Fleet simulations at 1980. The calendar years are referred as actual years where GHG emissions are calculated. On the other hand, model years are considered the date when new vehicles are introduced to the fleet stock.

The powertrain technologies studied in the calculations for evaluating the total environmental impact of LDV fleets are: gasoline ICEV, diesel ICEV, HEV, PHEV and BEV. For the case of Fuel Cell Electric Vehicles (FCEV), they are included in the model, although due to the very early stages of technology deployment it is difficult to estimate future rates of adoption. Therefore, they have not been considered in future scenario simulations.

The tool leveraged in this thesis, also called Fleet Model (FM), is an arithmetic assumption-based simulation model. By using historical sales data and gathering the fundamental characteristics of each country's LDV market, it is possible under specific assumptions to explore different strategies and quantify the consequent effects of attaining them. The logic behind Fleet Model calculations has been used in several previous reports before. A mathematical representation of the vehicle fleet size can be obtained by tracking the in-use stock, and introducing the frequency by which they are added or removed from circulation. Associating the age, distance travelled, powertrain technology and all other attributes to each vehicle it is possible to estimate their overall resultant activity.

This research exploits the benefits of such a simulation tool to understand better the consequences in terms of GHG emissions of a range of strategies regarding the evolution of LDV fleets in major European countries.

The objective is to leverage a comprehensive and robust model to identify the possible outcomes of adopting a set of strategies in the studied markets. Exploring a range of scenarios using a Fleet Model is very helpful in assessing the sensitivity of results to each of the parameters studied. Their relative impact in terms of GHG emissions is the ultimate output of the simulation calculations.

Other simulation tools have been considered as potentially useful for the type of interests contemplated in this work. Dynamic Models are interesting thanks to the feedback loops they include. Using technology diffusion methods, represented by differential equations, a simulation of innovation adoption can be carried out. Techno-economic and social influence parameters are contemplated and can be included within the model's calculation structure [72] [73]. Nevertheless, it is difficult to accurately estimate their effect and they add significant complexity to the calculation. When it comes to adapt these Dynamic Models to each case, the biggest challenge is the calibration of the feedback loops. As each country has its unique dynamic, the linked effects are not readily identifiable, being very difficult to replicate properly.

It is in that particular area that the Fleet Model simulation tool is especially effective, replicating exactly what is assumed in the characterization of each LDV market. As it is primarily built upon extensive arithmetic, the calculation is straight-forward. It is true that many parameters are related in some way, one with another; thus, it is tricky to isolate each individual contribution to final results. However, taking into account the objectives of this work and what are the available resources to build a robust and time-efficient simulation tool, it was decided that the Fleet Model is the most useful tool for answering the scoped problematics of this research.

The logic and structure of the model used is based on the Sloan Automotive Fleet Model, used for the scenario calculations for the "On the Road toward 2050" Report [74]. It was first employed by Professor's Heywood research group in 2004, who exploited the earliest generation of this model type [75]. The calculations done by the model can be briefly summarized with the following figure:

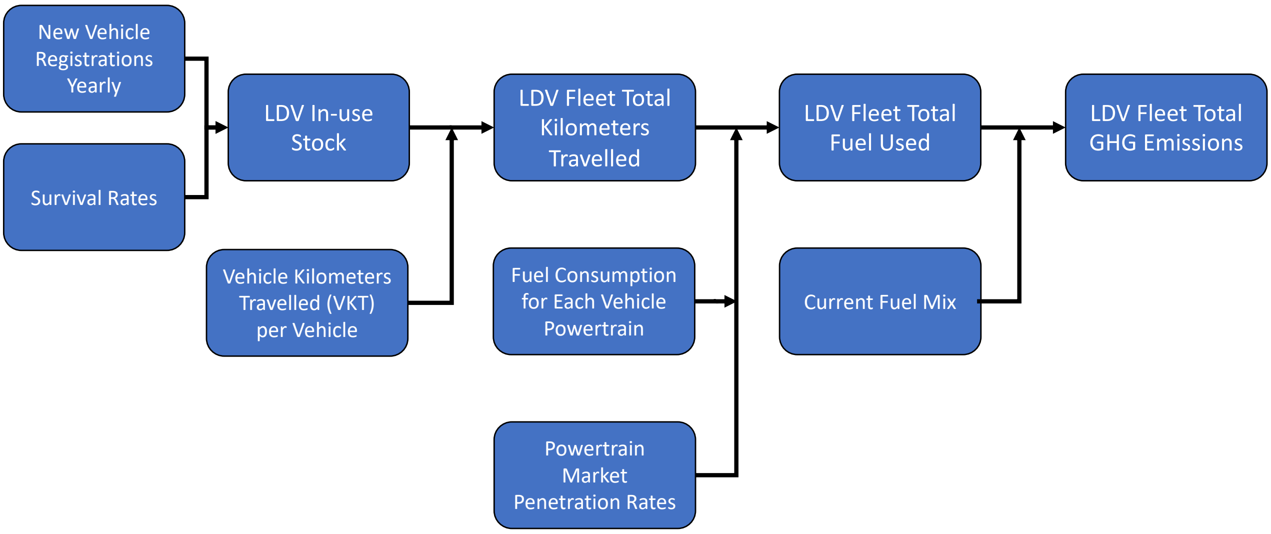

Figure 11: Block Diagram of the basic principle in Fleet Model's logic.

Starting with the number of new vehicle registrations per year and applying the corresponding annual survival rates, which represent the probability of a given vehicle not being scrapped, the model calculates the total LDV in-use stock. This constitutes the total number of vehicles in circulation at a given country and time. Including the Vehicle's Kilometers Travelled (VKT) for each vehicle it is possible to obtain the total number of kilometers the current fleet is travelling each year. Supported by the market penetration rates of each powertrain and what the fuel consumption is for every single one them, the model can estimate the total amount of fuel used for the propulsion of all the vehicles. The Fleet Model transitions from the actual fuel mix data to consider the carbon content per fuel volume and thus calculate the total GHG emission of the studied LDV fleet.

The following equation specifies the fleet GHG calculations in a given calendar year t for every powertrain technology p in the fleet:

$$GHG_t = \sum_{p} \sum_{MY=t_0}^{t} N_{t,p,MY} \cdot VKT_{t,MY} \cdot FC_{p,MY} \cdot CI_{t,p}$$

Where:

- $N_{t,p,MY}$ represents the current stock of in-use vehicles propelled with powertrain technology p, from model year MY in calendar year t.
- $VKT_{t,MY}$ is the number of kilometers travelled by a vehicle from model year MY in calendar year t.
- $FC_{p,MY}$ is the fuel – or energy - consumption of a vehicle's energy source using powertrain technology p which was first registered in model year MY, given in $L/_{km}$ or $kWh/_{km}$, depending on the type of propulsion system used.
- $CI_{t,p}$ is the carbon intensity of the vehicle using powertrain p. This shows the amount of gCO2eq emitted per energy resource consumed, in $gCO_2eq/_{L}$ or $gCO_2eq/_{kWh}$.

The amount of detail in the input data is what culminates into more realistic results. Nevertheless, the evolution of each of the parameters which contribute to the output calculation depends on several assumptions. While building the Fleet Model for each case, to obtain plausible results it is important to thoughtfully establish all the assumptions and the hypotheses. In the next section it is explained precisely how the development of the model as a functional simulation tool has been achieved.

II – Fleet model development

As mentioned above, the logic of the Fleet Model used in this research is inspired by previous simulation tools that were developed for the same purpose: to analyze the consequences of adopting a set of strategies and evaluate their relative environmental impacts. In this case, the fleet model has been adapted for the set of European countries that are studied in this work.

Going further, the amount of detail developed in the simulation tool used broadens the scope compared to previous existing Fleet Models. These models are built upon existing data and extrapolate into foreseeable future as defined by the assumptions. By adding more detailed information it is possible to obtain better-grounded starting situation for calculations to estimate future scenarios. It is important to thoughtfully build the model with more reliable datasets, since the assumptions are mainly set by understanding previous evolutions.

Data used to build the model

Several data sources are needed to obtain all the necessary information to develop a background grounded enough for the calculations to be meaningful. The Fleet Model initiates previous years before the actual date and builds the in-use stock of vehicles progressively until the current timeline commences. All the previous parameters included in the model go from 1980 to 2017. This is decided for having well-documented and extensive input data to feed the model. Using data from present date for some parameters would bring more difficulty, as in most of sources the data is still incomplete.

The sales profiles of each of the countries analyzed in this research represent the key element in order to replicate the most reasonable starting point. It is thanks to several accessible data sources provided by country governments and European institutions, that it is possible to recreate the sales trends for each LDV market. In some cases, the sales number needs to be extrapolated due to the lack of data.

To better quantify the particularities between each LDV country fleet it is necessary to a more complete detail on the sales. It is not sufficient to have the total number of sales in a given year. The historical sales trends need to be broken down into the different available vehicle powertrains. At the same time, vehicle types may vary widely. Even for a given propulsion system and vehicle size, their performance can differ significantly. Therefore, it is important to consider the segmentation of the vehicles constituting the fleet for each existing powertrain. However, this has to be done with caution as an “excessive” segmentation of the vehicle types and their powertrains could lead to unnecessary sophistication of the model, which becomes increasingly time consuming to build and modest benefits in the differences contributed by the additional detail. The proposed Light-Duty Vehicle segmentation is the one utilized in all Fleet Models for this thesis:

- **Cars:** This segment includes conventional four-wheel passenger cars. It is broad, containing small cars up to large wagon vehicles.
- **SUV:** Sport Utility Vehicles (SUV) is the category of vehicles which combines characteristics of on-road passenger vehicles, with some off-road elements such as high clearance or generally a four-wheel drive. They are also commonly known in European countries as 4x4s.
- **OLT:** This segment gathers all the vehicles which are large, have high weight and usually are used for professional purposes. Also, Other Light-Trucks (OLT) are mostly known as Light-Commercial Vehicles (LCV). It mainly consists of vans in European countries.

At each country and segment, there has been also a differentiation for each type of powertrain. Therefore, for each segment considered for the model calculations it also needs to account for the registrations per powertrain technology.

Car and SUV segmentation in market shares is similar regarding powertrain types, but there is a lack of more consistent data. That is why both have been assumed to follow very similar distributions regarding powertrain technology, but their absolute number is scaled by the total share of the segment. For OLT, the segmentation by powertrains can be done, as there is reliable data available. In Appendix A are gathered the details regarding every sales data set used and its reference.

To obtain the resultant stock of in-use LDV it is not only necessary to consider the new registrations, but also to simulate how these vehicles are removed from circulation. This is taken into account in the Fleet Model by using survival rates. There are no consistent data to characterize the scrappage rates at each different country. Consequently, they are represented by a time dependent function whose output is the probability that a vehicle will have to survive at a given year with respect to their registration year [76].

$$Survival\ Rate\ (t) = 1 - \frac{1}{\alpha + \ e^{-\beta\ (t-t_0)}}$$

Where:

- t_0 is the median life-time of a corresponding model in years.
- t is the time variable evaluating the survival rate at the current year.
- α is model constant set to 1, though in some literature that is considered over restrictive [77]
- β is a growth parameter dictating how fast vehicles are removed and can be adapted to each segment.

This then allows the model to calculate how new LDV registrations will be removed from the model progressively, simulating the actual fleet dynamics. At the same time, survival rates are a factor inherent to each country, as the fleet turnover is triggered differently. To gather the particularities of the studied European countries, the fleet data has been supported by the evolution of the median lifetime in years. However, calculating the median life-time for a precise year new registration number of vehicles is unrealistic with the available data, especially from dates before the digitalization of information where the data is blurred. For most recent model years, it is extremely challenging as the vehicles are still on the road and it is hard to predict how the aging effect will influence them.

In order to build into the Fleet Model, the particularities associated with each country's LDV fleet aging, and consequently with future Survival Rates for every model year, have to be considered. Therefore, it is needed to leverage a new methodology for determining the median lifetimes to match in-use data with the output of the simulation. Leveraging vehicle in-use data helps to identify what the evolution of the fleet stock should be like. At each model year, all the parameters in the time dependent Survival Rate function are kept constant, except the median life-time which is calibrated to replicate how the number of in-use vehicles fluctuates. This allows the simulation to replicate the market dynamics individually at each country studied. The results show remarkably similar trends between the model stock calculation and the actual number of LDV in circulation.

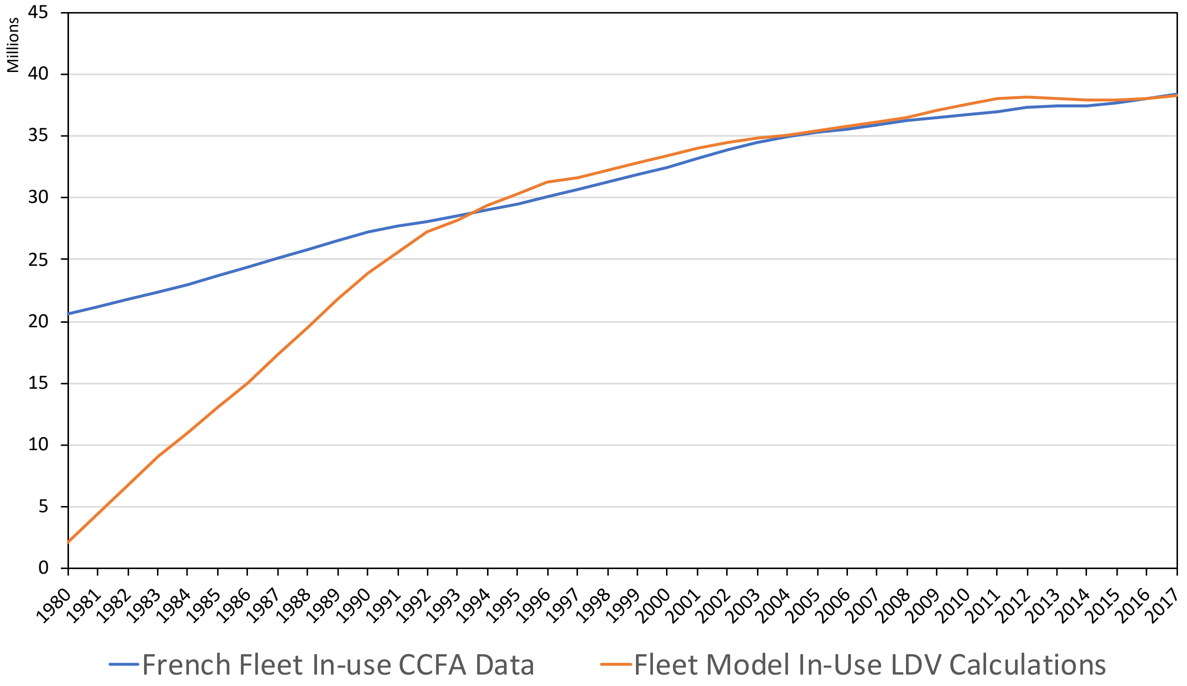

Figure 12: In-use vehicle stock Fleet Model Calibration. Case applied to French LDV fleet

The above figure shows how the Fleet Model calculations converge towards real in-use LDV fleet data, following an initial start-up evolution. It can be appreciated that at the current model timeline, in 2017, the difference between the source input data and the simulation calculation is negligible. Same procedure is replied at each different market. At the start of Fleet Model calculation, the vehicle in-use stock is zero. It is progressively built into the simulation, reaching after a period latency a stationary situation where the model converges towards the real in-use

LDV fleet. Therefore, in the previous figure it takes close to 10 years to reach actual vehicle in-use numbers. For each country studied, the comparison between current vehicle stock and Fleet Model calculations can be found at Appendix B.

The Vehicle's Kilometers Travelled and its evolution is an important parameter that characterizes the fleet behavior. It represents how many kilometers are travelled by any LDV registered in a precise year, and how this number shifts while aging. Two different trends must be differentiated here: the evolution year by year of new vehicles entering the stock fleet and how these new vehicles divide their total mileage over the years on the road.

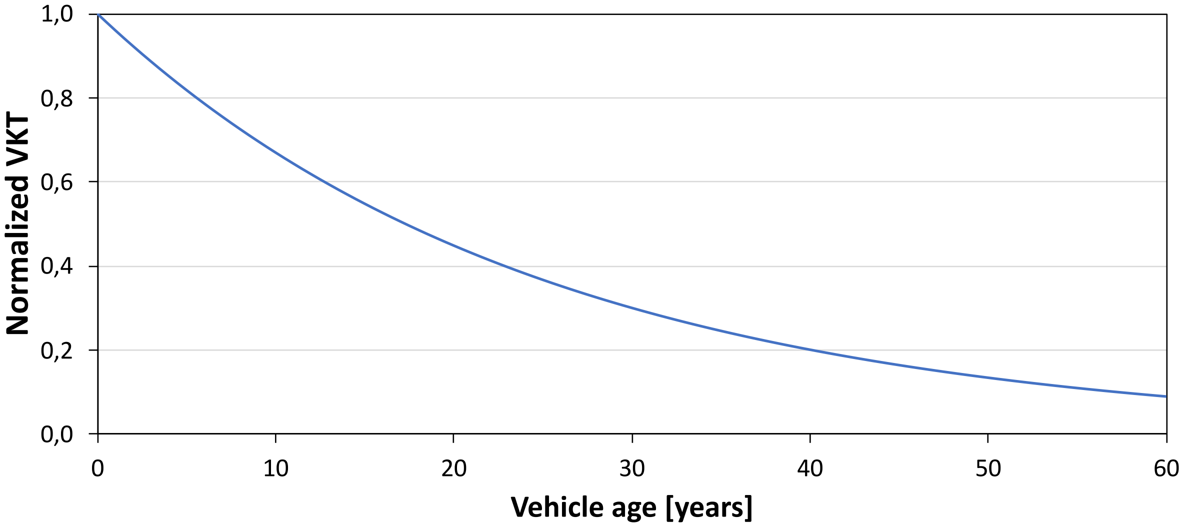

Figure 13: Normalized VKT evolution curve with vehicle aging [78].

The equation for describing VKT as a function of the calendar year is [78]:

$$VKT_t = VKT_{new} \cdot e^{-rt}$$

Where:

- VKT_t is the actual vehicle kilometers travelled per year at year t.
- VKT_{new} is the vehicle kilometer travelled per year of a brand new vehicle.
- r is a slope parameter adjusting the speed which VKT decays over.

As mentioned before, VKT_{new} changes depending of the model year that the vehicle is included into the in-use car parc. In several studies, it is documented that the average number of kilometers travelled for a Light-Duty Vehicle has been increasing at least until about 10 years of age. This trend is applied beyond current data-based simulation timing; nevertheless, some studied sources suggest that this numbers are reaching a plateau and recently, the tendency is being reversed [79].

In addition, average fuel consumption (FC) – and energy consumption for electrified powertrains – input data is necessary to estimate the current and earlier levels. Fuel-efficiency is what determines how many energy units – implicitly stated in the volume and composition of a petroleum fuel or explicitly in the quantity of electricity – are required in a given type of powertrain to cover a precise distance. Of course, these values depend on many factors such as the driving behavior, the weight and size of the vehicle, and the ambient conditions. In an effort to reduce this spread in fuel-consumption, even in a particular model, standardized cycles are required in order to certify vehicle fuel consumption and emissions. Thanks to these data and specific reports from market segmentation and individual model sales, the average fuel consumption of a LDV country fleet can be determined [80]. Based on several sources, it is possible to develop a methodology to gather input data from previous vehicle's fuel consumption and obtain its progression with time. In Appendix C, all the information regarding the development of the fuel consumption datasets is explained.

Last but not least, the Fleet Model has to convert the actual amount of energy consumed per year by the total LDV fleet into GHG emissions. The relevant carbon intensity (CI) factors are used this thesis' calculations. The scope of this research has enlarged the Fleet Model consideration by accounting for the emissions not only while the vehicles are circulating on the road, but also for the emissions related to the vehicle production and the fuel drilling and transportation, as well as for the necessary electricity production to propel electrified powertrains. This approach benefits the model through a broader life-cycle perspective by analyzing the total GHG emissions of the LDV fleet. It not only accounts for the emissions produced on the countries' territory, it includes a representative value indicating how significant are these overall vehicle emissions and fuel production.

For emissions accounting on the vehicle production side, the LCA methodology used takes into account all their processes and their energy use employed for manufacturing a vehicle. Then they are converted into the total amount of gCO2eq emitted during the whole process. The quantities used for each powertrain technology are detailed in the following table.

Table 5: GHG Emissions related to vehicle production process by powertrain technology for car segment [81] [82].

Powertrain technology	Emissions associated with vehicle production in metric tons of CO2eq / vehicle
Gasoline	7,5
Diesel	7,5
HEV	9,5
PHEV	11
BEV	14,5
FCV	11,25

Since this kind of calculations are difficult to carry out for each of the European countries studied in this work, these values will be adopted in every Fleet Model application. Nonetheless, the emissions related to manufacturing process are directly linked to the vehicle size and weight, which differs from one model to another. These differences should be considered in order to estimate precisely the vehicle production emissions. Since the Fleet Model includes different vehicle segments, for each one of them it scales the total GHG emissions per vehicle produced - typical values shown in Table 5 - by the average relative weight difference with respect car segment.

When petroleum fuels are used, the emissions accounted for fuel production are also a non-negligible contribution to LDV GHG emissions. The crude oil after being extracted from lower soil layers, needs to be transported to refineries where it is treated to reach exploitable compositions for current internal combustion engine vehicles. It is then distributed as gasoline and diesel to refueling stations. These actions are all required to supply adequate fuel at the distributing locations, they are also considered as a contribution to global warming effects derived from LDV fleet. This amount represents around 20-25% of the total energy used by the vehicle [83]. This is often known as the Well-to-Tank (WTT) emissions, while the purely on-the-road associated emissions are Tank-to-Wheels (TTW) emissions, giving the total gCO2eq emitted by unit of volume for a particular fuel composition. The overall emissions are considered the Well-to-Wheels (WTW) emissions.

Leveraging the factors that characterize each fuel type, it is possible to find their carbon intensities.

Table 6: Petroleum fuel characteristics considered in Fleet Model calculations

Petroleum fuel	Emissions equivalents in gCO2eq emitted / L of fuel	Energy density in MJ / L of fuel
Gasoline	2300	32,2
Diesel	2630	35,8

The carbon intensities of WTT and TTW emission then can be deducted:

Table 7: WTT and TTW carbon intensities for Gasoline and Diesel fuels adopted in Fleet Model

Powertrain technology	WTT emissions in gCO2eq / MJ	TTW emissions in gCO2eq / MJ
Gasoline	23,8	71,4
Diesel	24,5	73,5

For electrified vehicles powered by grid electricity, the emissions are displaced. The energy generation mix, which represents how the different energy sources are combined to supply electricity for users' needs, is then responsible for the GHG emissions. Combining the emissions for every source of electrical energy is not trivial, as their nature differs significantly. Renewable energies are responsible for cleaner electricity as they are not directly linked to any kind of emissions while operating. In contrast, fossil fuel energy sources release their energy through combustion reactions and are able to transform it into useable electricity. Nuclear energy is a particular case among the energy sources, as it uses fission reactions of radioactive isotopes and by means of Rankine cycle produces electrical energy. They are considered as clean energy source, but nuclear plants are associated with a degree of risk of radioactive exposure to their surroundings. However, they all entail a certain degree of GHG emissions. Combining LCA data from different sources, allows the Fleet Model to quantify the emissions of every energy source contributing to electricity production. Using European Commission data [84], it is possible to calculate the average generation mix in each country of the European Union. Data for Norway is extracted from governmental sources and the International Energy Agency (IEA) [85] [86] [87]. The next table summarizes the carbon intensity factors considered for each energy source to calculate total emissions associate with recharging plug-in vehicles in each country.

Table 8: Energy sources considered in Fleet Model calculations and associated carbon intensity factors.

Energy sources	Carbon Intensity factors in gCO2eq / kWh
Solid fossil fuels, peat and products, oil shale and oil sands [88]	1038
of which hard coal [88]	960
of which brown coal [88]	1050
Oil and petroleum products [88]	778
Natural gas Combined Cycles [88]	443
Nuclear [88]	10-66
Hydro [88]	10
Wind [88]	7
Solid biofuels and renewable wastes [88][89]	35
Biogases [88]	11
Liquid biofuels [89]	203*
Solar PV [88][90]	32
Geothermal [88]	38
Tide, Wave and Ocean [91]	53
Wastes non-Renewable Energy Sources [88]	430

** Only considers the biofuel production LCA average value, accounting for the Land usage to cultivate corn bioethanol and not the associated emissions to the energy production complete life cycle.*

However, carbon intensities in Table 7 represent average values among all the extensive variety found in the literature. Each LCA is conducted under its own boundaries, leading to have a significant spread for some of the electricity sources.

III – Common assumptions inherent to all calculations

When estimating future situations, it is always important to settle a set of assumption. In that way it is possible to define boundaries and control under which circumstances the predictions will be more accurate. It is crucial while developing a model which evaluates the impact of forecasted scenarios, to establish these assumptions as thoughtfully as possible. Well-grounded hypothesis on the estimated calculations lead to more coherent results. For the development of the Fleet Model calculations a wide set of assumptions is needed to replicate future foreseeable LDV fleet dynamics.

Some of the assumptions are inherent to all the calculations. This helps establish a stable base shared in all explored scenarios.

Market penetration shares evolution

How future sales penetrations will evolve in the future years is hard to predict. Therefore, while exploring the different set of targeted 2050 market penetration rates, it is important to define what is the trend each powertrain technology is assuming to attain them. For every case, independently of the estimated levels of adoption in the forecasted timeline, the path between both will be achieved linearly.

$$Market\ Sales\ Penetration_{p,t} = Market\ Sales\ Penetration_{p,t-1} + \ \Delta\ Adoption\ rate_{p}$$

Where:

- $Market\ Sales\ Penetration_{p,t}$ is the actual market sales percentage at calendar year t, for powertrain technology p.
- $Market\ Sales\ Penetration_{p,t-1}$ is the previous calendar year $t-1$ market sales percentage, for powertrain technology p.
- $\Delta\ Adoption\ rate_{p}$ represents the market sales penetration variation year by year, for powertrain technology p, at a given scenario.

At the same time, the adoption of AFV vehicles has been slower in for Light-Commercial Vehicles than for passenger cars. Due to their bigger size and the more important gap in convenience between combustion engines and electrified powertrains, the transition towards greener technologies is likely to need more time. Therefore, it is important to take it into account in the market penetration rates. That is why for every scenario explored, the targeted level of penetration for HEV and AFV is more modest than for cars or SUV.

Fuel consumption evolution

For estimating the future fuel consumption of each vehicle segment and each powertrain technology, a recursive learning evolution curve has been defined. As it appears in some reports, the trends of fuel consumption change are usually referred to the average percentage of improvement with regard to the precedent year [92]. While figures go down and improvement rates (IR) remain unchanged, the absolute improvement in fuel consumption year by year diminishes. In the Fleet Model, the improvement percentage rates are considered constant year by year and the following equation describes how it is adopted in the simulation tool.

$$FC_t = FC_{t-1} \cdot (1 + IR)$$

Where:

- FC_t is the actual fuel consumption at calendar year t.
- FC_{t-1} is the fuel consumption of the previous calendar year $t - 1$.
- IR is the improvement rate.

Sales evolution and car ownership

The sales evolution represents the number of new vehicles that are registered in the LDV fleet and this number changes year by year. It is an important parameter as it sets the growth of the market itself. Introducing more or less vehicles into the market has an immediate impact on the GHG emissions, as its contribution is linked to the size of the LDV fleet. For that reason, the assumption on the sales evolution needs to be set with a common logic to all countries, but respecting the particularities and foreseeable trends of each one of them. How LDV sales evolve is mainly related to vehicle demand and car ownership perception.

While vehicle demand is linked to consumers' willingness to purchase new vehicle, whether to renew their old one or to buy it for the first time, car ownership is intrinsic to each society. It entails the pride of owning a car, but also its convenience against other means of transportation. Since most of the European cities have increasingly extended public transportation networks and traffic congestion in big city centers is under its way to be extremely reduced, car ownership levels are not likely to increase. Also, rail transportation is becoming a more popular means of transportation to connect different cities. That is why, LDV sales are regarded unlikely to increase from that point of view. However, the high level of independence they offer assures them a major role in future of mobility, as current operating costs still allow to be a very convenient road transportation method. In the Fleet Model developed for the different European countries studied in this work, the car ownership perception is considered constant. As a matter of fact, this leaves to sales demand from the consumers side to rule the sales evolution.

Each LDV market size has an unequivocal relationship to its country population. In this LDV fleet simulation tool it has been assumed that variations year by year in sales number are driven by the future population prospects [93]. Fleet turnover mechanisms are more complex and this represents a wide simplification, as various external factors - such as automotive companies' efforts in introducing new models, decision-making process of consumers or nations macroeconomic situation – interfere in the real process. The resultant outcome is challenging to estimate. That is why in the Fleet Model, it has been adopted that LDV market enlargement is linked to the average rate of population variation in each country. However, the vehicle total in-use stock with their age.

LDV fleet median life-time evolution

To have the complete fleet turnover mechanism included in the model, after setting how new vehicles will be introduced in the fleet, it is also crucial to define how they will be removed. In order to estimate how vehicles are scrapped in the model, Survival Rates are associated to new registration. As seen before, using the same Survival Rates formula the model associates the probability of a model year vehicle to remain in circulation, a certain number of years after its registration. For LDV introduced in the Fleet Model after 2017, it is needed to evaluate how mean life-time of those vehicles will be.

As technology improves for all powertrains, the vehicles tend to become more robust and reliable. This reduces the need to replace them as often as expected previously. The consequent effect is a reduction in the scrappage rates of LDV fleets, which can be interpreted as an aging of the number of new introduced vehicles. As a matter of facts, it represents an average increase of the time they remain in-use, influencing directly the in-use vehicle stock. To recreate this effect in the Fleet Model, the Survival Rates formula is modified by an increase in median life-time. In all countries it has been assumed the aging happens at the same rate, as differences are difficult to estimate.

Quantifying the effect of aging out of the scope of this research. But the effect has an important influence in fleet turnover. That is why, for every calculation it is considered a linear increase in LDV median life-time of 1,65 years, with regard to 2017.

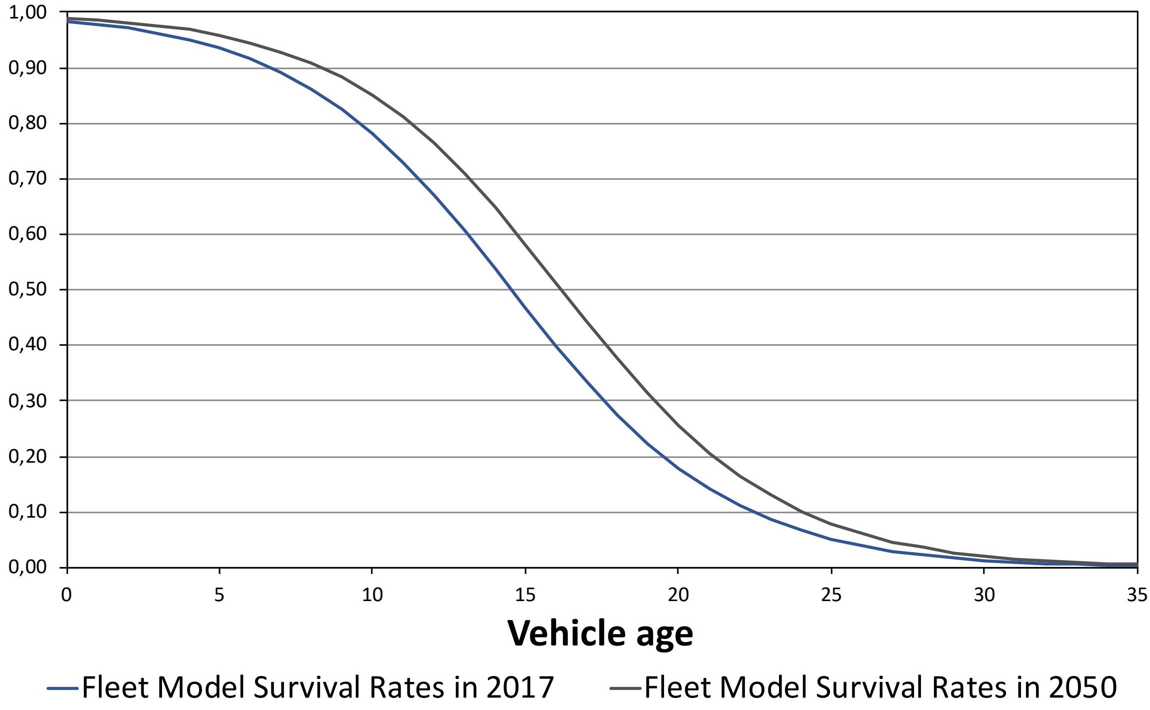

Figure 14: Survival Rates formula comparison between 2017 and 2050 with evolution over vehicle age.

The Survival Rates comparison highlights how significant is the fleet aging factor introduced in the model. The graph shows the effect of increasing the median lifetime and how it is been translated to the probability of a vehicle being scrapped. It is also important to underscore that 35 years after their entry in circulation, all vehicles from a given model year are considered scrapped.

Sales by segment adoption

Sales are distributed among all the segments included in the simulation tool. Representing how this distribution will look like in the calculated scenarios is crucial, as vehicles have different performances and thereby their GHG emissions differ from one segment to another. Basing on previous data of their market shares it is possible to replicate the tendencies.

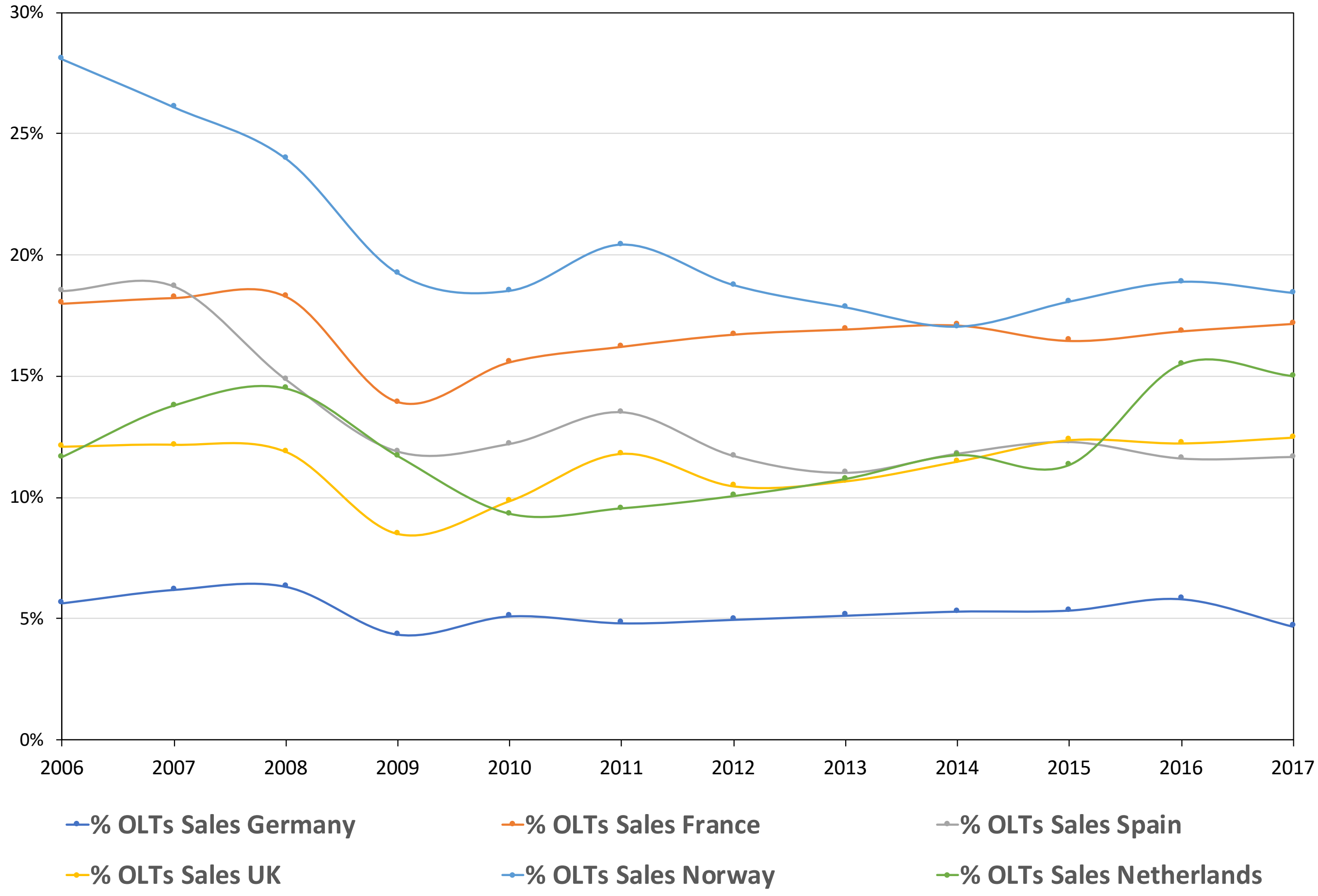

Figure 15: Market share percentage evolution for OLT segment from 2006 to 2017 in major European countries

For OLT - or Light commercial Vehicles – segment market share in the Fleet Model, the forecasted trend is assumed to stay constant for each country analyzed. Based on previous data from multiple sources - all references in annex A – the shares have been fluctuating around the same figure, as it can be appreciated in the previous graph.

For SUV and Car segment it is more difficult to assess what would be the more predictable situation.

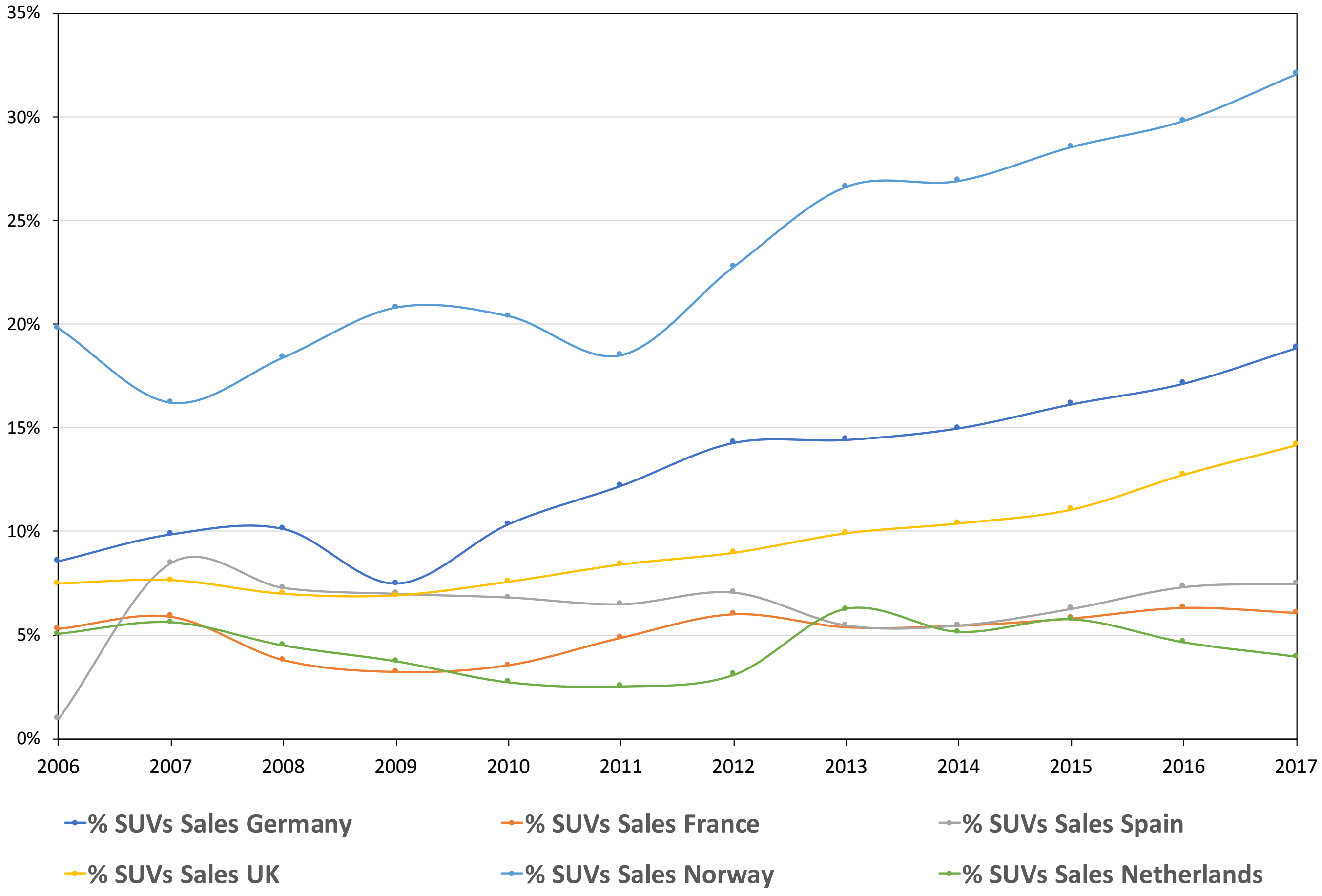

Figure 16: Market share percentage evolution for SUV segment from 2006 to 2017 in major European countries.

While some countries like Norway, Germany or United Kingdom, the SUV segment adoption has been well spread and the relevance in market sales is rapidly increasing, other European markets such as France, Spain or Netherlands have not seen their shares modified over the last years. Therefore, different profiles have been developed for the Fleet Model, in order to able to explore different scenarios regarding segment adoption.

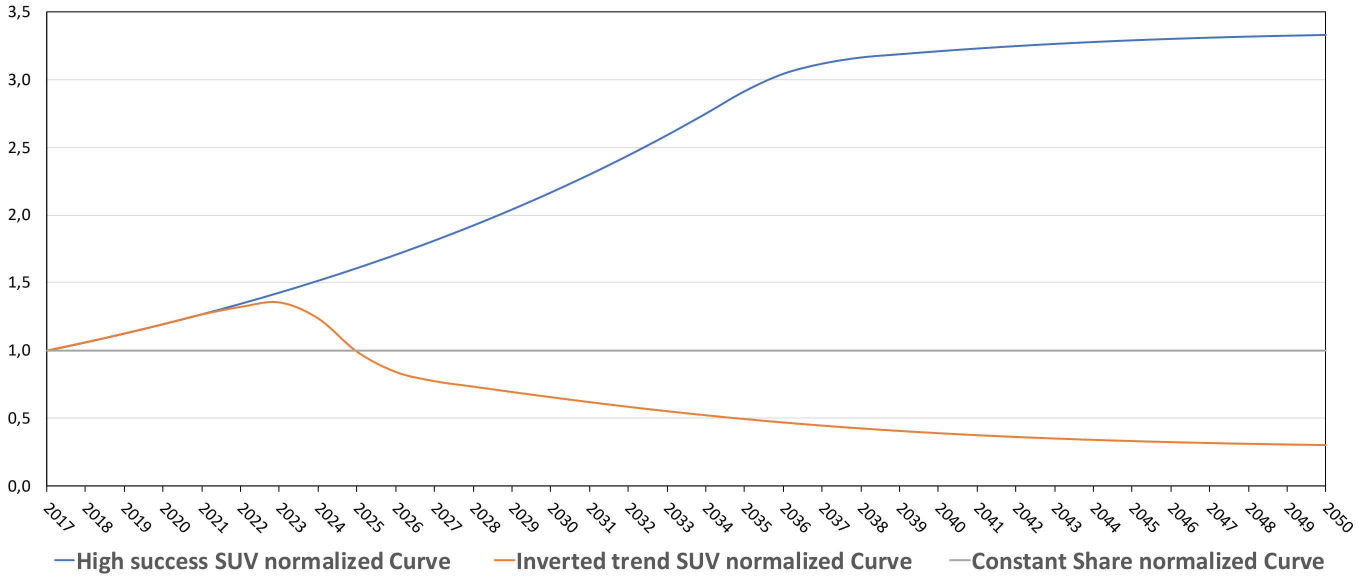

Figure 17: Different SUV adoption normalized trends assumed in the Fleet Model for exploring different scenarios

Figure 17 shows the different normalized curves allowing to explore several scenarios with respect vehicle segment adoption impacts. Since the curves rely on starting market share at 2017 for each country, future calculations consider previous progress in adopting a particular vehicle segment.

VKT evolution for upcoming Model Years

The plateau of kilometers driven per vehicle, attained by current LDV in modern European, suggests that these numbers are likely to decrease. Some countries have already experienced these trends, while others are still very steadily keeping the VKT numbers [94]. In the Fleet model it has been considered that these numbers will slightly decrease over the upcoming years, reverting the previous trend observed in the past years.

All new registrations vehicle kilometers travelled have been estimated in function of 2017 data. The VKT changes from one country to another, and is linked to the assumption that an average LDV vehicle will travel 250.000 km during their entire useful life.

Electricity grid use and future generation mix

Plug-in electrified powertrains rely on the grid to be able to recharge. Therefore, it is assumed that AFV will use the electricity of the grid with an average generation mix, among all the available electricity sources in a particular country. All information included in the Fleet Model regarding electricity production can be found at Appendix D.

For estimating the future electricity supply in each country, it is based on actual countries trends to develop more a more sustainable grid. Most deployed renewable energy sources are estimated with an optimistic realistic extrapolation. At each country, nuclear energy actual perception is considered for estimating its future prospects [95]. As some countries have decided to become independent from nuclear energy in their electricity production process, it is needed to include this information in the Fleet Model while assuming future energy mix.

Also, the technological and environmental improvements are considered in every calculation, reducing the carbon intensities of each energy source recursively each year. This takes into account the efforts in improving the technologies itself and transforming them to greener means of energy procurement.

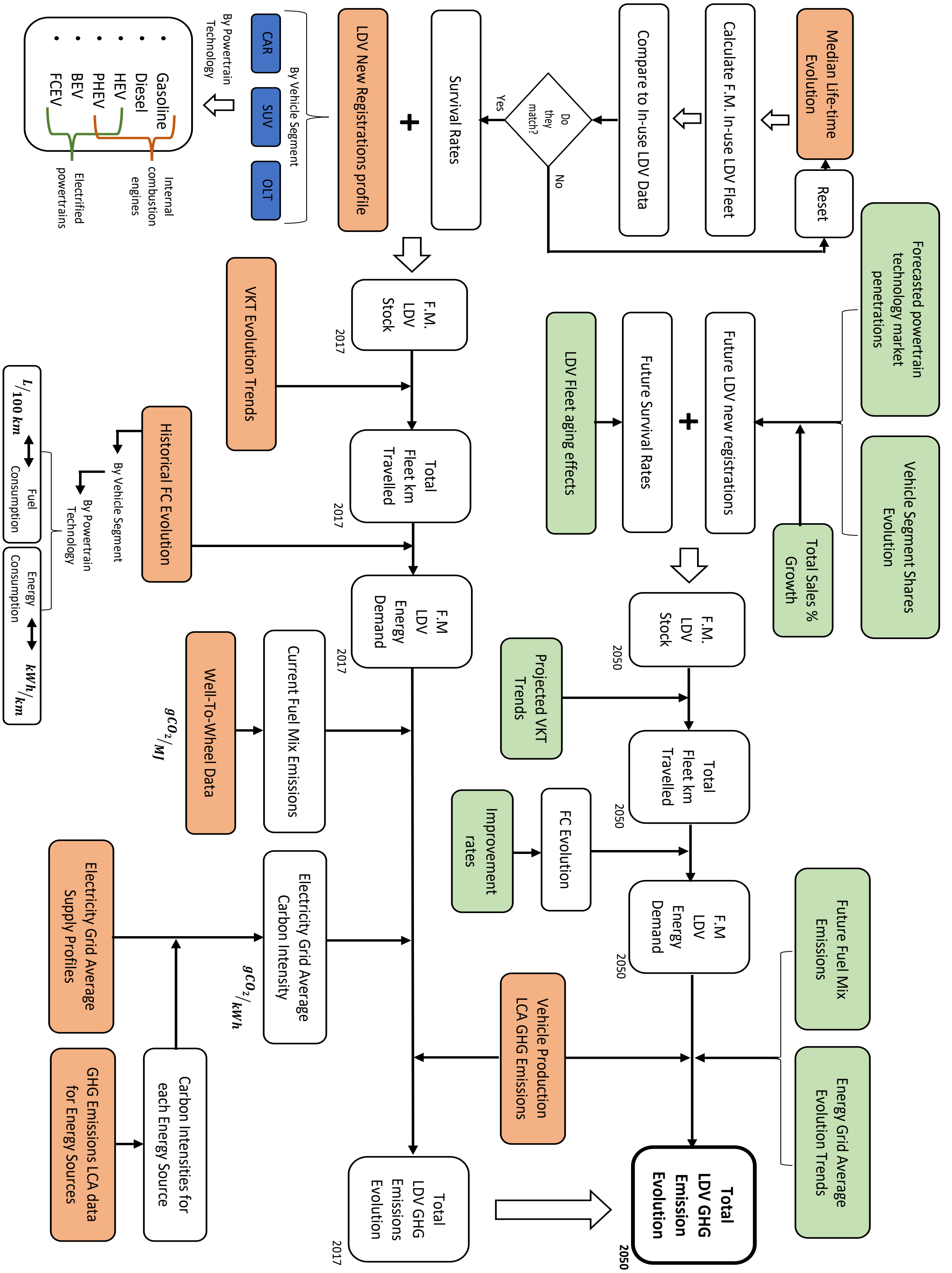

Figure 18: Fleet Model data flow diagram.

The above figure describes in detail the structure of the Fleet Model, as well as all the input parameters used in each scenario calculation. All the different elements aggregateence which leads to effectively simulate the total LDV HG emissions rates inodel data flow diagram presented in Figure 18, orange boxes represent input data while green boxes are assumptions thoughtfully established to evaluate future LDV fleet's impact on GHG emissions. Exploring the sensitivity and analyzing the ese assumptions are the main goals of this thesis. The next chapter describes the parameters of interest for this research and the ranges within they are estimated to change.

Chapter 5 - Scenarios

Once the simulation tool has been developed, the next step was to define a set of scenarios, to enable to quantify the relative importance that key influencing parameters have in terms of GHG emissions. The goal of this chapter is to present the scenarios that were conceived to estimate the potential of several strategies aiming to reduce road transportation environmental impact. These strategies involve LDV fleet improvements such as increasing the emphasis in fuel consumption reduction or having more rapid AFV adoption over the six European countries analyzed.

The analysis starts by defining a reference scenario for what is a plausible path for each country studied in this research. This reference scenario represents the backbone for scenario sensitivity analysis carried out. In the next section, how the individual country reference scenarios were established is discussed, as well as the details of the starting situation in every country.

I – Reference Scenario definition

Establishing reference scenarios is needed to have a likely base situation to assess all the actions analyzed. Even if all are envisaged under the same logic, they need to respect each countries' precise situation. For major European countries studied, except Norway, it seemed appropriate that the market penetration of electrified powertrains – sum of HEV and AFV – would be 55% of the total vehicle sales in 2050. In contrast to the rest of the studied countries where the rates of adoption of these vehicles by 2017 are comparable, the Scandinavian country has already reached around 50% of electrified vehicle penetration by that date. It, being unlikely for Norway to have only a 5 percentage points increase in the electrified vehicle sales in the following 33 years, it was decided to treat Norway differently. This methodology leads to different rates of adoption for each powertrain technology. Also, the ratios between each of the electrified powertrains are kept constant all over their adoption. This means that the ratio of AFV over HEV sales and the ratio of BEV over PHEV sales remain unchanged as these greener technologies are introduced into the market.

Regarding to vehicle fuel-economy in reference scenario, it was fixed throughout the calculation's timeline, a one percent yearly reduction of the fuel-consumption of a given vehicle segment and powertrain the year before. This sets the improvement rate at -1% in every European country.

The electricity generation mix evolution is assumed to evolve reducing its carbon footprint progressively. In each country, the trend of introducing more renewable energies is identified. Extrapolating linearly this tendency of greening the electricity grid constitutes an optimistic, yet realistic evolution. The calculations replicate this evolution and calculate year by year, the average carbon intensity per MJ of electricity produced. More details are described at Appendix D.

The details comparing the market share situations in 2017 and 2050 for the different reference scenarios in each LDV fleet studied are explained below.

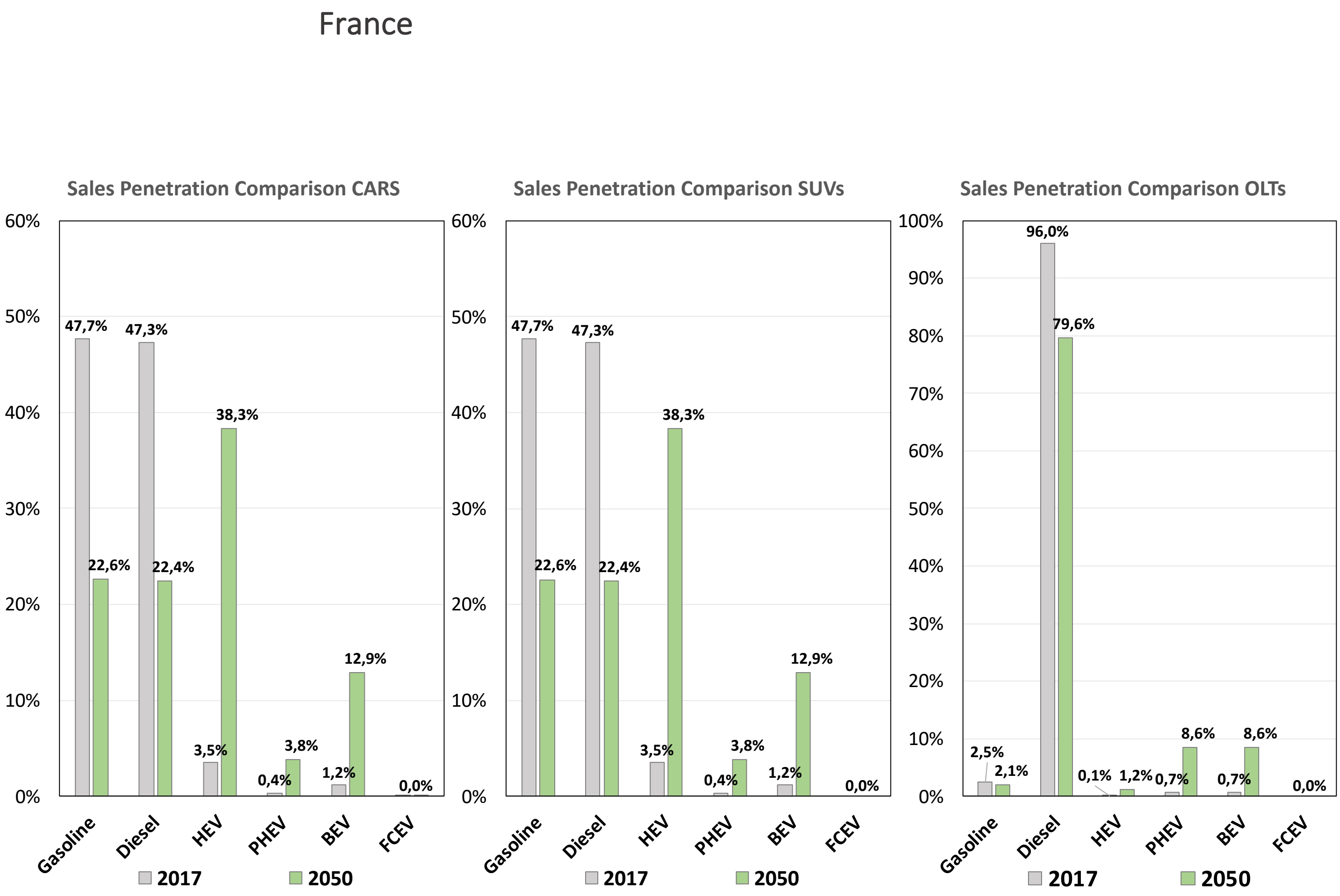

Figure 19: Sales penetration variation between 2017 and 2050 in French LDV market by segment and powertrain technology for reference scenario.

France is a country where BEV adoption is becoming significant, starting at sales rates in 2017 above 1,2% for Car and SUV segments. However, PHEV presence remains modest. Regular HEV have had more important success as their adoption is more uniformly spread out, as consequence of their higher convenience. For OLT segment, Diesel are predominant as also found in the rest of reference scenarios.

Germany

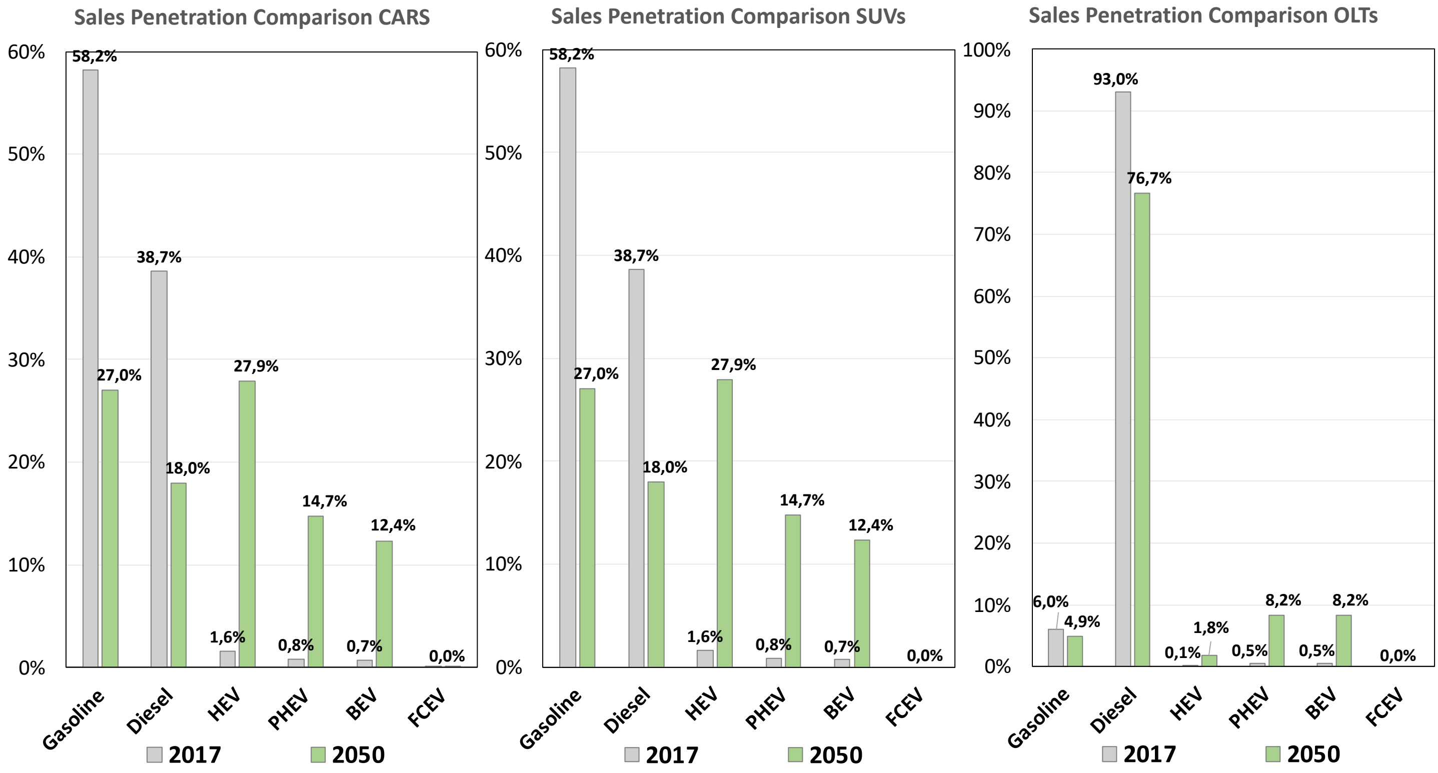

Figure 20: Sales penetration variation between 2017 and 2050 in German LDV market by segment and powertrain technology for reference scenario.

In Germany gasoline cars are have more popularity than diesel for the LDV market. Also, though AFV are considered relevant, their absolute sales numbers in the total market sales are fewer than in other European countries by 2017.

The Netherlands

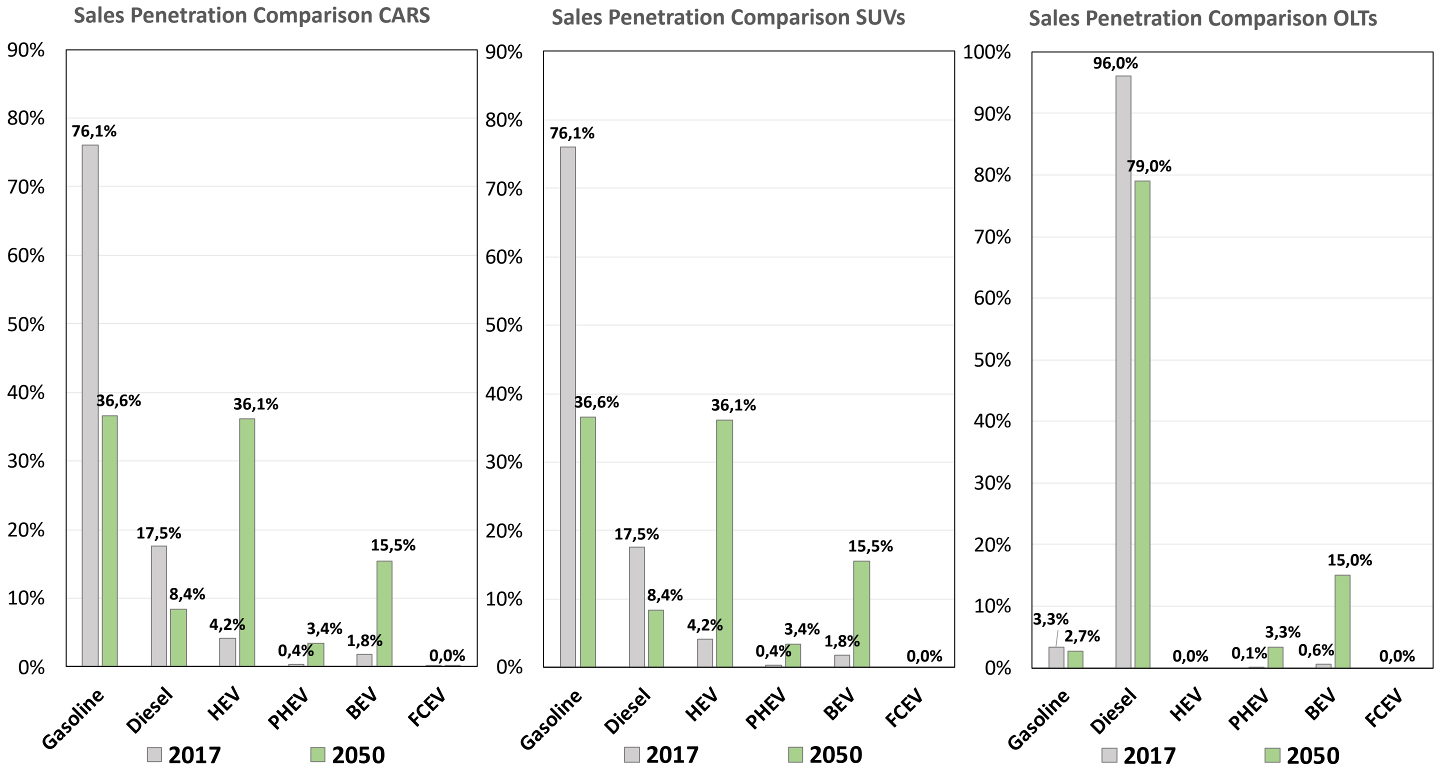

Figure 21: Sales penetration variation between 2017 and 2050 in Dutch LDV market by segment and powertrain technology for reference scenario.

The Netherlands represents a well-advanced country in terms of LDV electrified powertrains adoption. All together, the market share of PHEV and BEV is above 2% by current starting date of future year calculations (2017). In previous years, higher rates of PHEV adoption have been experienced, but this trend now seems to be shifting towards BEVs.

Norway

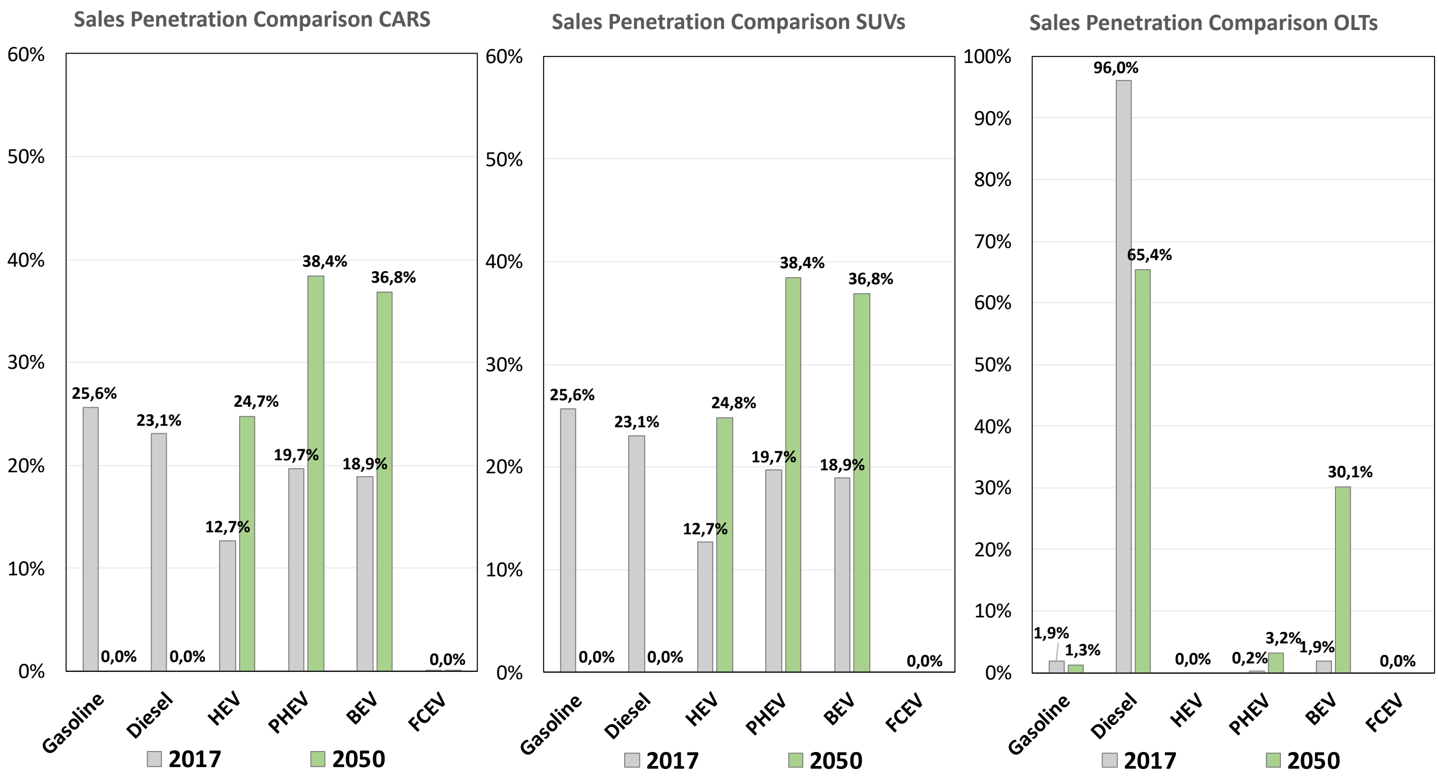

Figure 22: Sales penetration variation between 2017 and 2050 in Norwegian LDV market by segment and powertrain technology for Reference Scenario.

As Figure 22 shows, Norway is a very special case for analysis. By 2017 the current rate of adoption of HEV and AFV together was close to 50%. More remarkable is the rate of adoption for PHEV and BEV which both separately reach almost 20% of the total number of sales by that year. After considering the actual progress in the introduction of plug-in electric vehicles in Car and SUV segment in Norway, it seemed appropriate to set as the reference scenario for Norway the achievement of market share of 100% for BEV, PHEV and HEV (all together) by 2050. For OLT vehicle segment, this adoption has experienced less rapid less rapid AFV introduction. That is why the AFV calculation in 2050, that the rate of adoption would be still less rapid than in the other segments.

Spain

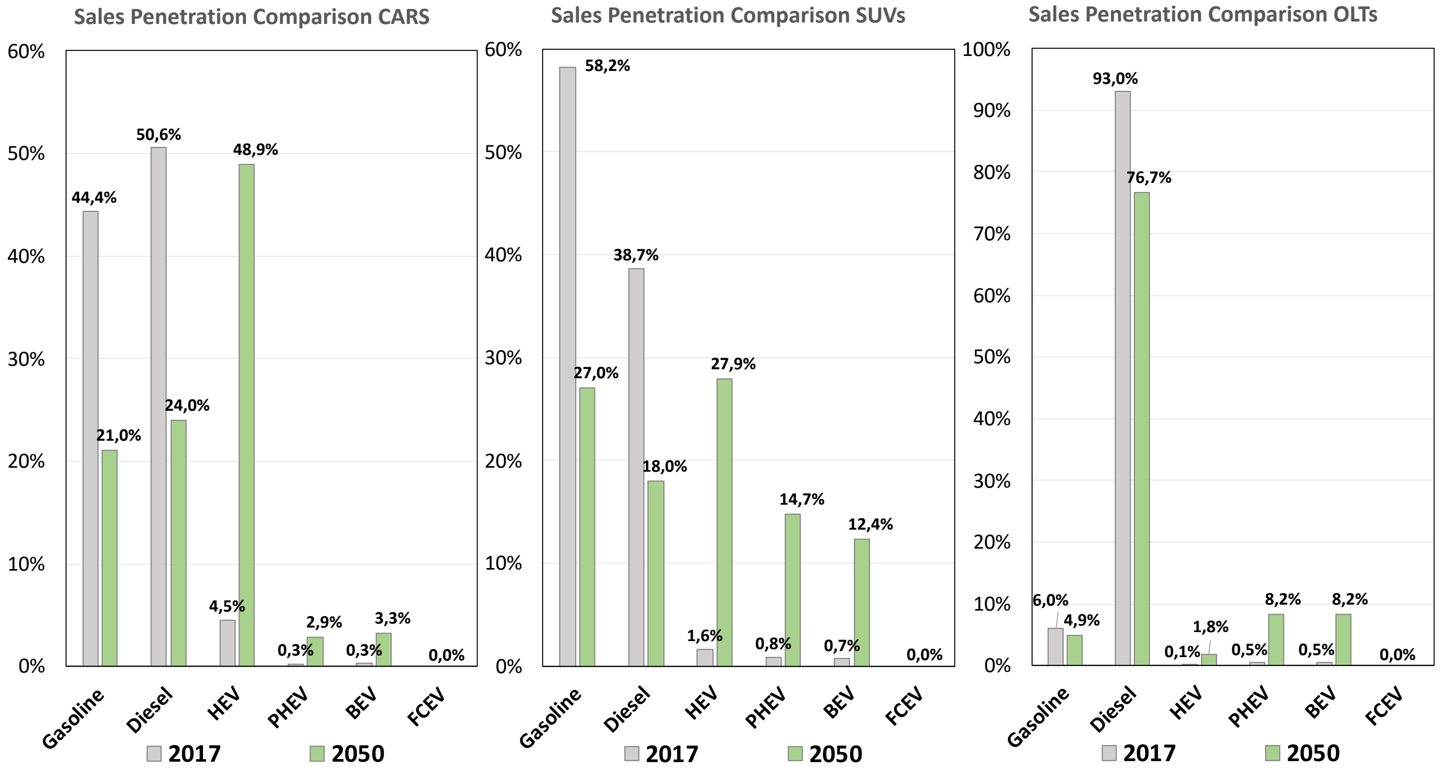

Figure 23: Sales penetration variation between 2017 and 2050 in Spanish LDV market by segment and powertrain technology for Reference Scenario.

The most noteworthy aspect of the Spanish LDV market is the high presence of HEV in 2017 market share [96]. Despite the fact of not having any kind of incentives, regular hybrid vehicles have performed surprisingly well. The negative point is the slow rate of adoption of AFV which are almost non-existent at present date. This allows room for a wider margin of improvement in terms of fleet GHG emissions. Also, to highlight that diesel vehicles still have an important presence at nowadays market shares.

The United Kingdom

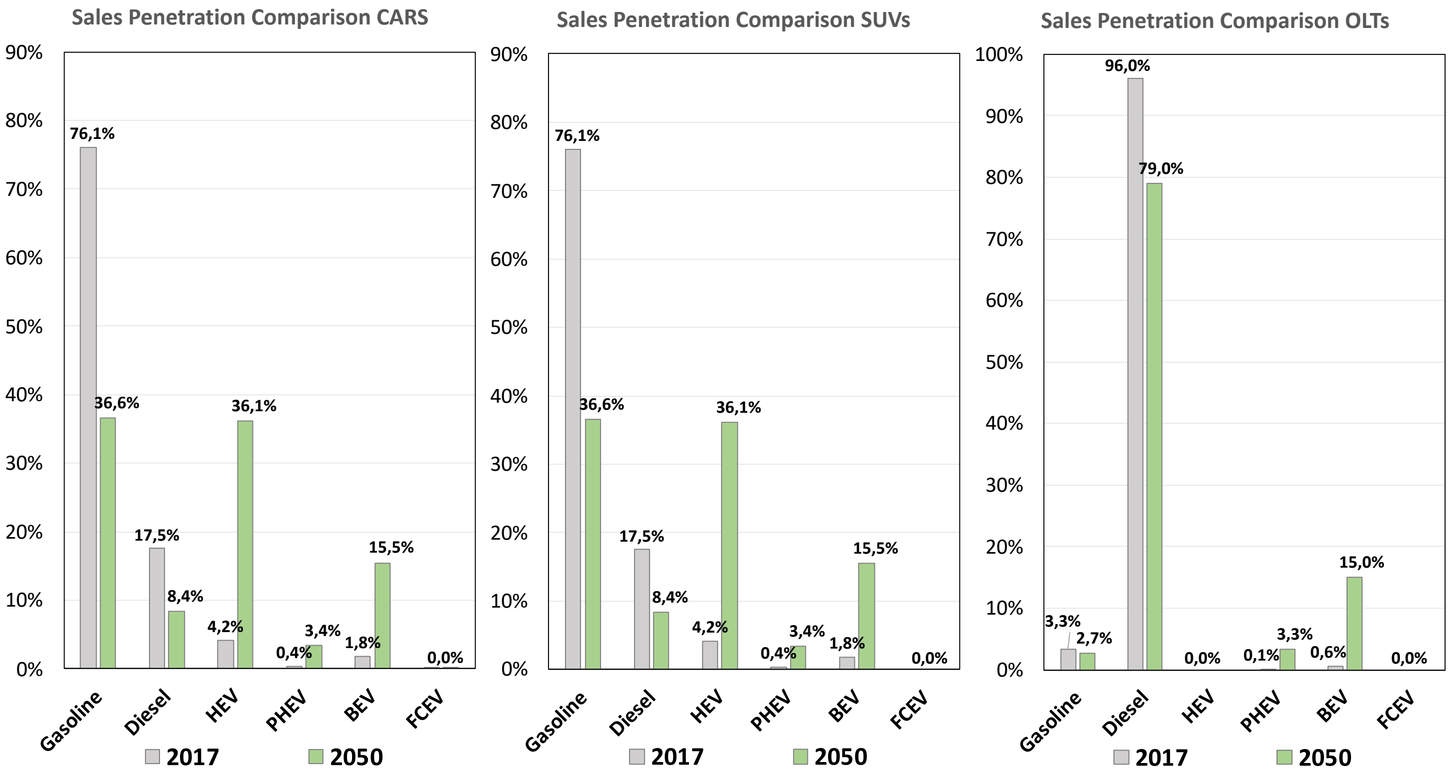

Figure 24: Sales penetration variation between 2017 and 2050 in British LDV market by segment and powertrain technology for Reference Scenario.

The British LDV market shows, from the AFV side, by a significant presence of PHEVs. At the starting calculation market situation, they represent 1,4% for both Car and SUV segment. Regular hybrids have seen an important adoption as well. Note the important "dieselization" of the OLT segment market, reaching shares close to 100% in 2017.

Summary of reference scenarios parameters by country

Table 9: Reference Scenario Fleet model parameter comparison between major European countries studied.

Country	**Sales growth per year**	**FC improvement rate per year**	**Median lifetime increase per year**	**Market share $\frac{AFV}{HEV}$ Ratio**	**Market share $\frac{BEV}{PHEV}$ Ratio**
France	0,26%	-1%	0,05 years	0,44	3,35
Germany	-0,11%	-1%	0,05 years	0,97	0,84
Netherlands	0,09%	-1%	0,05 years	0,52	4,50
Norway	0,86%	-1%	0,05 years	3,04	0,96
Spain	-0,13%	-1%	0,05 years	0,13	1,14
United Kingdom	0,42%	-1%	0,05 years	0,70	0,36

Listed in Table 9 are the most important parameters in the Fleet Model simulation for each of the Europeans countries analyzed. Following Tables 10 and 11, summarize the current (2017) input market shares of all the powertrains and the ones assumed in 2050 for the reference scenarios.

Table 10: Reference scenario market shares comparison between major European countries studied in 2017.

Country	2017 Car & SUV Segment Market Shares					2017 OLT Segment Market Shares				
	Gasoline	Diesel	HEV	PHEV	BEV	Gasoline	Diesel	HEV	PHEV	BEV
France	47,7%	47,3%	3,5%	0,4%	1,2%	2,5%	96,0%	0,1%	0,7%	0,7%
Germany	58,2%	38,7%	1,6%	0,9%	0,7%	6,0%	93,0%	0,1%	0,5%	0,5%
Netherlands	76,1%	17,5%	4,2%	0,4%	1,8%	3,3%	96,0%	0%	0,1%	0,6%
Norway	25,6%	23,1%	12,7%	19,7%	18,9%	1,9%	96,0%	0%	0,2%	1,9%
Spain	44,4%	50,6%	4,5%	0,3%	0,3%	3,2%	96,3%	0%	0,3%	0,3%
UK	53,4%	42,0%	2,7%	1,4%	0,5%	0%	99,4%	0%	0,3%	0,3%

Table 11: Reference scenario market shares comparison between major European countries studied in 2050.

Country	2050 Car & SUV Segment Market Shares					2050 OLT Segment Market Shares				
	Gasoline	Diesel	HEV	PHEV	BEV	Gasoline	Diesel	HEV	PHEV	BEV
France	22,6%	22,4%	38,3%	3,8%	12,9%	2,1%	79,6%	1,2%	8,6%	8,6%
Germany	27,0%	18,0%	28,0%	14,7%	12,6%	5,0%	76,7%	1,8%	8,3%	8,3%
Netherlands	36,6%	8,4%	36,1%	3,4%	15,5%	2,7%	79,9%	0%	3,3%	15,0%
Norway	0%	0%	24,7%	38,4%	36,8%	1,3%	65,4%	0%	3,2%	30,1%
Spain	21,0%	24,0%	48,9%	2,9%	3,3%	2,6%	79,1%	0%	9,2%	9,2%
UK	25,2%	19,8%	32,3%	16,7%	6,0%	0%	81,7%	0%	9,2%	9,2%

II – Exploring the sensitivity of parameters involved in scenario calculations

The straightforward logic of the Fleet Model allows us to run many scenario calculations and analyze the direct impact of gradually shifting the variables important in the overall simulation. Exploring the sensitivity of the factors which predictably will have a potential benefit in reducing GHG emissions is important to assess their comparative relevance. The following section presents the different parameters evaluated in this work. The objective is to obtain a relative quantification on the gains obtained while enhancing these strategies.

HEV and AFV future total sales penetration variations

For evaluating the effect of having more electrified powertrain vehicles on the road, the first sensitivity analysis assumes greater sales shares of HEV and AFV in 2050. It shows how GHG emissions will be affected while shifting towards having more representation of electrified powertrains. Taking the reference scenario as starting point, with 55% of market penetration by 2050 the simulation horizon, variations of the final total market share of sum of HEV and AFV were done. These changes in the adoption levels are achieved by applying multiplication factors. However, when increasing or decreasing the sales percentages, all the ratios between the different types of powertrain technology considered in the Fleet Model are unchanged, with regard to the reference scenario.

Table 12: HEV and AFV sales penetration in 2050 sensitivity analysis comparison between the different scenarios studied.

Scenario	HEV + AFV dropped by 50%	HEV + AFV dropped by 25%	Reference Scenario	HEV + AFV increased by 25%	HEV + AFV increased by 50%
Car & SUV **HEV + AFV market share by 2050**	27,5%	41,3%	55%	68,8%	82,5%
OLT **HEV + AFV market share by 2050**	9,2%	13,8%	18,3%	22,9%	27,5%

Emphasis on reducing fuel consumption

Inverting more resources in making actual technologies more fuel efficient is a strategy which realizes a direct benefit in GHG emissions. Therefore, by exploring the different expected situations regarding the fuel consumption evolution over time can give a good estimate of the benefits of reaching these levels. The values were chosen based on several historical trends observed in European countries.

Table 13: Fuel consumption improvements rates comparison in studied scenarios.

Scenario	**Very low emphasis on FC reduction**	**Low emphasis on FC reduction**	**Reference Scenario** **Regular emphasis on FC reduction**	**High emphasis on FC reduction**	**Very High emphasis on FC reduction**
Improvement rate per year	-0,1%	-0,5%	-1%	-1,5%	-2%

Applying an improvement rate of -1% yearly reduction in fuel consumption is equivalent to assuming close to a 30% progress by 2050, with respect to 2017 average values.

AFV over HEV sales penetration ratio variations

The relationship between AFV and HEV market shares is another factor considered in this thesis. Performing a sensitivity analysis on the ratio between both of their respective market shares will gives a clearer understanding of the consequences of shifting towards greater adoption in the different types of electrified powertrains. Each country starts from current proper ratio. This quotient is modified by applying a multiplication factor to in the different scenarios considered, as shown in Table 14. While analyzing these scenarios, the ratio of BEV over PHEV market share was kept constant at the reference scenario value.

Table 14: Comparison of the different multiplication factors applied for the $\frac{AFV}{HEV}$ Ratio sensitivity analysis in studied scenarios.

Scenario	**Very high HEV adoption**	**High HEV adoption**	**Reference Scenario** **Current $\frac{AFV}{HEV}$ Ratio**	**High AFV adoption**	**Very high AFV adoption**
Multiplication Factors	All HEV	1/3	1	3	9

BEV over PHEV sales penetration ratio variations

In a similar way as the preceding case, a sensitivity analysis for the BEV over PHEV ratio was done. Varying the ratio with a set of scenarios examines the effect of having a higher or smaller success in adopting one powertrain technology rather than the other. To obtain a clearer sense of the impact of changing this parameter in every country studied, a higher plug-in electric vehicle penetration scenario is chosen as starting point for the sensitivity analysis. The chosen base scenario is high AFV adoption from previous analysis, which is actually the reference scenario $\frac{AFV}{HEV}$ Ratio multiplied by 3.

Table 15: Comparison of the different multiplication factors applied for the $\frac{BEV}{PHEV}$ Ratio sensitivity analysis in studied scenarios

Scenario	**Very high PHEV success**	**High PHEV success**	**High AFV adoption Current $\frac{BEV}{PHEV}$ Ratio**	**High BEV success**	**Very high BEV success**
Multiplication Factors	All plug-in vehicles PHEV	1/4	1	4	All plug-in vehicles BEV

However, it is important to keep in mind that for every calculation in this sensitivity analysis, the $\frac{AFV}{HEV}$ ratio is kept as in the reference situation. The sum of AFV and HEV penetration is remains at 55% by 2050 in all cases.

Car and SUV segment sales share adoption trends

Evaluating the impact on emissions of adopting one specific vehicle segment rather than another is also an interesting. As a vehicle's fuel consumption scales proportionally with its size, shifting to bigger vehicles would lead to an overall increase in the average fuel consumption of the fleet. Some European markets, mainly influenced by the American LDV market trends are experiencing these changes in average vehicle size distribution. Important differences exist between the current SUV market shares in some of the studied countries. By applying the different SUV adoption trends seen previously to each of the markets in their reference scenario, it is analyzed the sensitivity of shifting the rate of sales to greater size LDV.

Electricity grid improvement

The GHG emissions intensity of the electricity used to recharge plug-in electric vehicles has a direct influence on the total LDV emissions. Since EVs recharge their batteries from the grid, it is important to identify the sources which generate the electricity in order to account for the real effectiveness of rechargeable vehicles in mitigating road transportation's global warming effects. The electricity grid is a singular aspect of each country energy sector. Relevant policies vary from one country to the another and the resources available differ as well, it is important to include the specific situations in each country in the Fleet Model calculations.

From the current electricity generation mix in 2017, it is possible to extrapolate the trend toward a greener grid and apply it in future forecasted years. The same methodology has been applied for each country. In Appendix D, all the information is presented regarding the carbon intensities evolution trends of each of the six studied countries and the resulting generation mix in 2050.

In order to analyze the sensitivity of impacts to improving the grid in each of the LDV fleets, three different strategies are evaluated. All the strategies used here are applied for the reference scenario with the $\frac{AFV}{HEV}$ ratio multiplied by three – High AFV adoption scenario - in each country. The first strategy considered, which is also the one used for all reference scenarios, extrapolates the actual greening tendency of the grid. The other two options represent the worst- and best-case scenarios:

- A scenario where the grid is not developed at all, staying at the current (2017) level source mix.
- Another scenario which represents the option of recharging every single one of the plug-in electric vehicles in the fleet with fully green electricity, accounting for no emissions.

Using these extreme cases, which go beyond likely future expectations, will show the potential benefits of having much more environmentally respectful electricity generation sources.

Chapter 6 – Results

Presenting the results obtained with the scenarios explained previously is the main focus of this chapter. All the sensitivity analysis calculations were carried out for each country. Each study provides quantitative assessment of the benefits of adopting various strategies to reduce GHG emissions from LDV fleets. A major interest in performing this type of analysis is to explore the potential impacts individually of key parameters, and compare their effectiveness in each country studied. The extensive number of variables involved in the scenario calculations opens up a wide range of possibilities that need to be explored.

I – Presentation of the reference scenario results

Reference scenario results are presented as baseline cases for each country studied, and are the central case used to perform the sensitivity analysis. Taking into account the specific characteristics of each European country LDV fleet and primarily based on the evolving rates of AFVs adoption, from 2017 to 2050, it shows the changes in the emissions impact of each country's parc over time, under the assumptions described previously.

It is important to emphasize on the fact that all the results described in the research take into account the GHG emissions resulting from the vehicle production and the fuel or electricity supply. The impact associated changes depending on the vehicle size and the powertrain technologies adopted. As more electrified powertrains are introduced into the in-use vehicle fleet, the percentage of emissions that vehicle production is responsible for becomes more significant. This is mainly due to the battery manufacturing processes which are high energy-intensive, and hence have a higher carbon footprint.

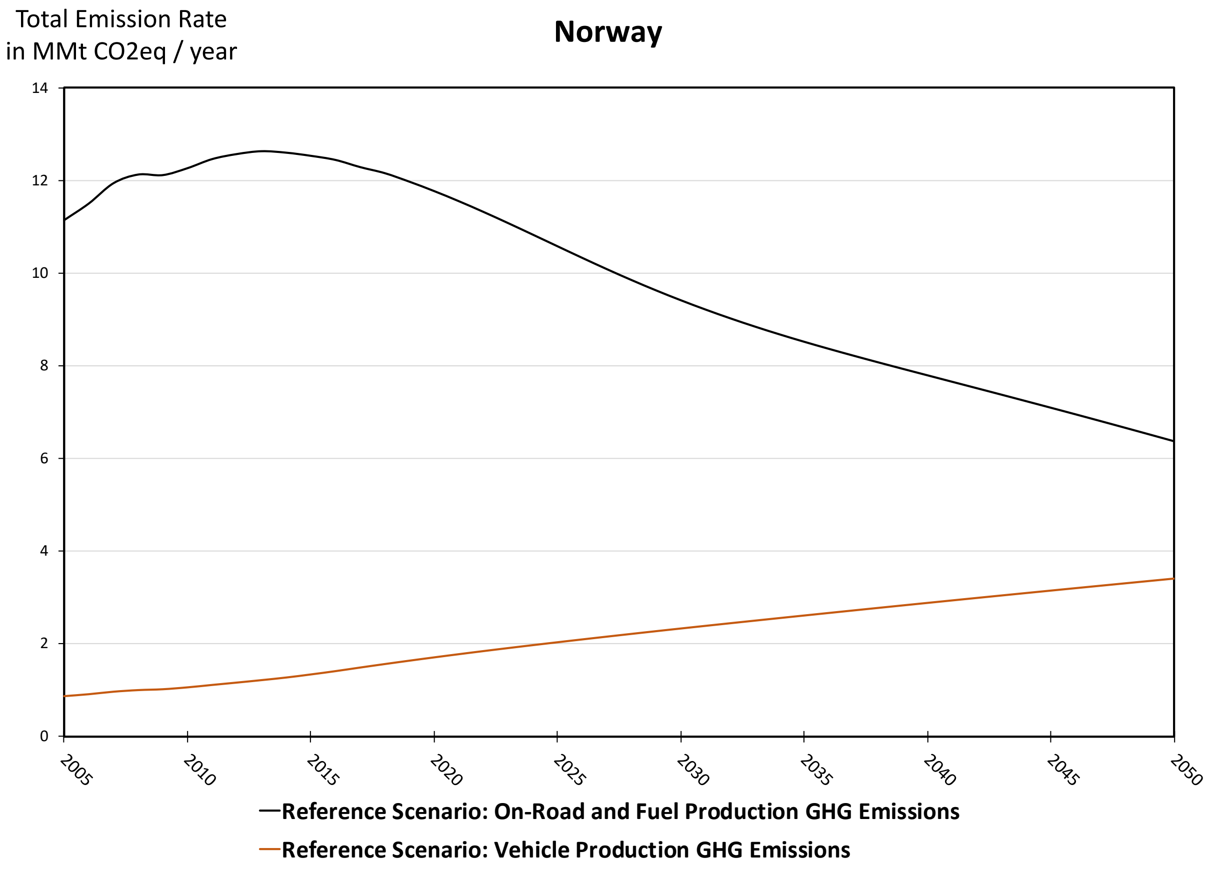

Figure 25: Total GHG emissions rates comparison in Reference Scenario between vehicle production and on-road vehicle usage with fuel production for Norway's LDV fleet.

As shown for Norwegian LDV fleet in Figure 25, the vehicle production emissions rise considerably. This is linked to the progressively higher adoption of EVs while approaching 2050. Consequently, the on-road ICEVs GHG tailpipe emissions are effectively reduced, though part of the emissions gain is shifted to EVs production process. Overall, GHG emissions decrease. However, the percentage of general vehicle production emissions goes from 11% in 2017 to almost 35% of the total LDV emissions in 2050.

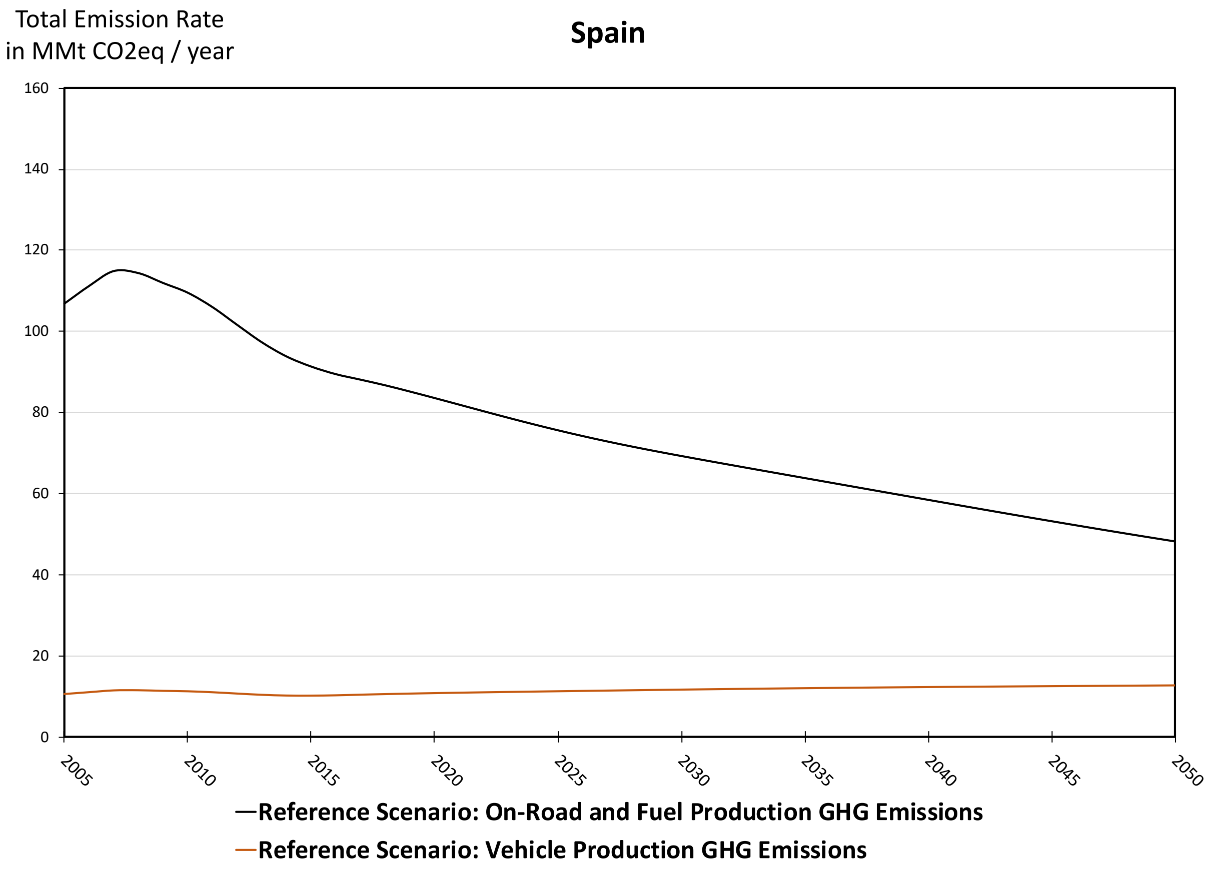

Figure 26: Total GHG emissions rates comparison in Reference Scenario between vehicle production and on-road vehicle usage with fuel production for Spain's LDV fleet.

For Spain, - and similarly in the other European countries studied - as the fleet is still mainly composed of vehicles having a combustion engine, the effect seen Norway's results are smaller. In this case, the vehicle production emissions percentages change from 11% in 2017 to 21% in 2050.

Giving a wider scope to the results and representing a more complete LDV environmental impact, the sum of on-road, fuel or energy production and vehicle production is included in each of the scenarios for the six countries analyzed.

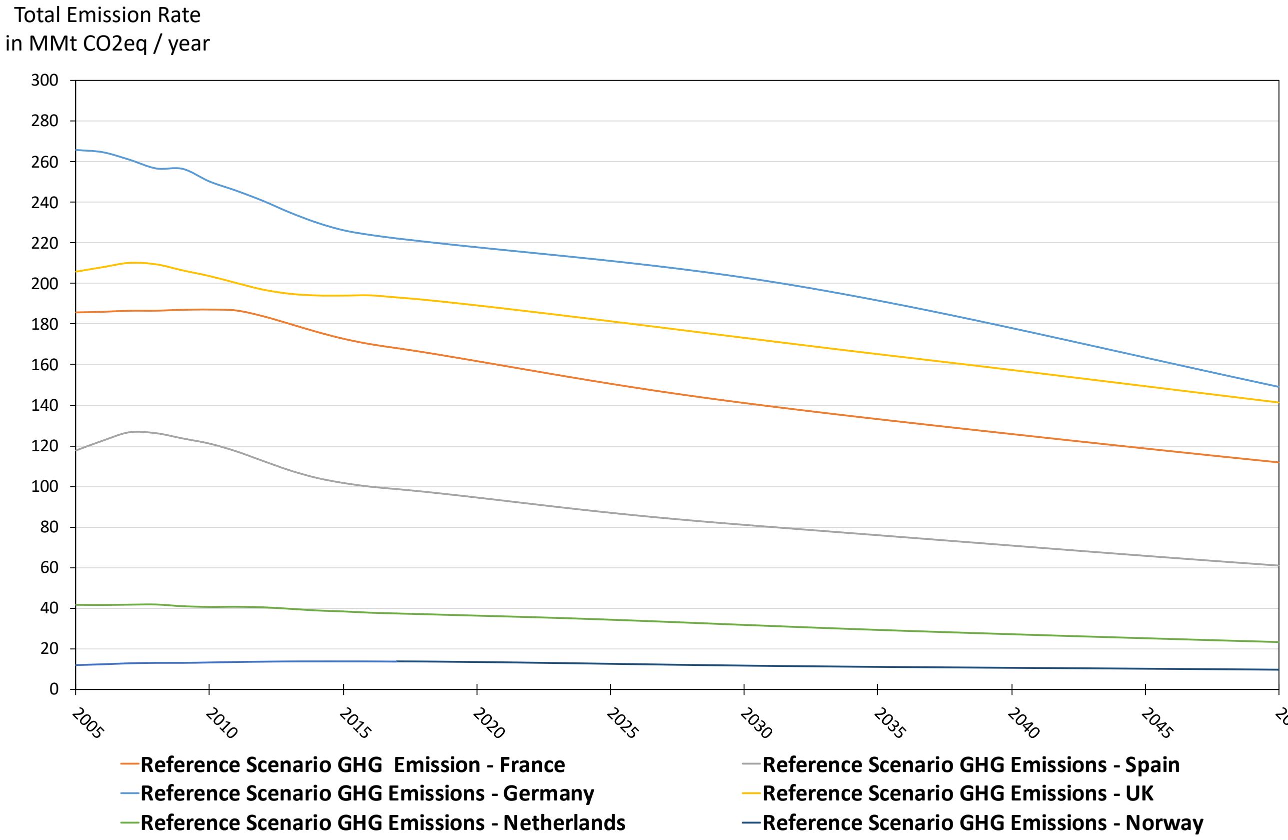

Figure 27: Comparison between total LDV fleet GHG emissions rates for the six major European countries studied.

A comparison of the total GHG emissions of the different LDV fleets is shown above. The curves reveal the evolution of LDV fleets total emission rates for their reference scenario. It also helps to compare the contribution in absolute terms. For the studied countries' LDV contributions to global warming decrease in all reference scenarios. The relative spreads partially reveal the differences in size between the different car parcs studied.

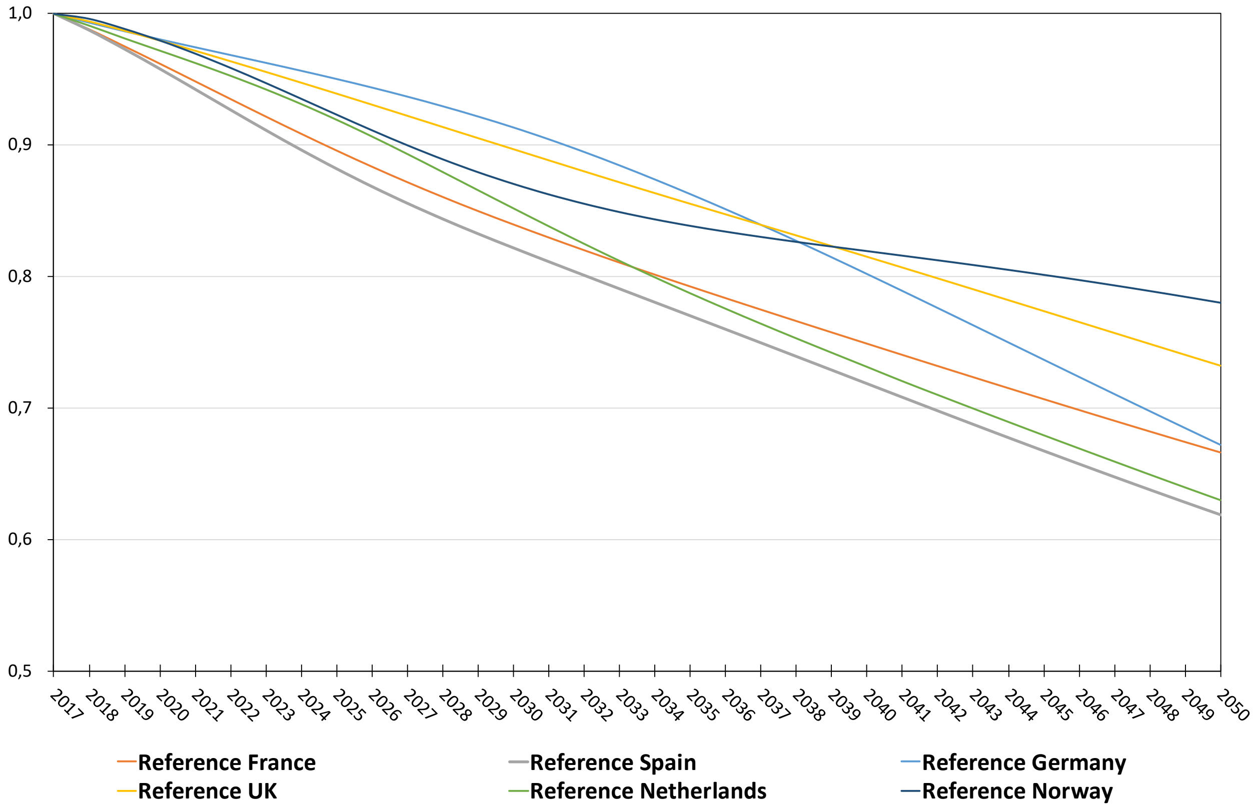

Figure 28: Comparison between normalized LDV fleet GHG emissions rates for the six major European countries studied. All emissions rates are referred to 2017 total LDV levels.

In order to be able to understand better the potential that electrified powertrain technologies have to effectively reduce road transportation’s contributions to global warming, LDV fleet total GHG emissions curves are normalized in Figure 28. All values are referred to 2017 emission levels in each of the countries for reference scenarios. It shows more precisely the potential benefits of introducing greener vehicles to the in-use fleet, in a foreseeable situation.

In the following section, a summarized overall view of the results produced in this research is presented, highlighting the key results conducted in this research. The most comprehensive curves for each of the sensitivity analysis are shown.

II – HEV and AFV total sales penetration, 2017 to 2050 - Results

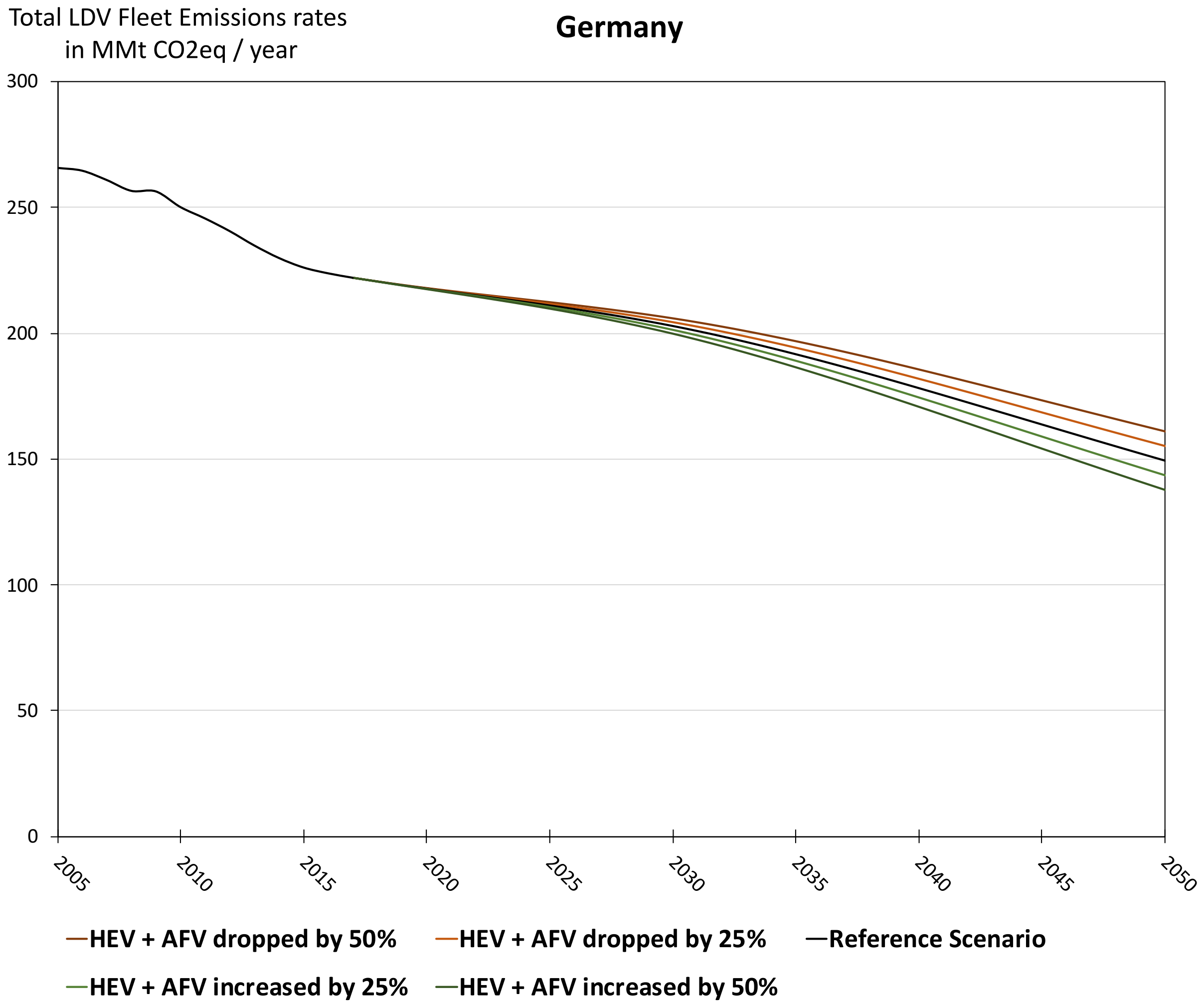

Figure 29: Total LDV fleet GHG emission rates for Germany. Sensitivity analysis results of electrified powertrains market penetration variations in 2050.

In Reference Scenario, AFV + HEV market penetration reaches 55% in 2050. Variations in the final market share of electrified powertrains are performed in this sensitivity analysis by factors specified in each scenario.

In Figure 29 appears the sensitivity analysis performed for German LDV fleet. The emissions rates are shown for the different scenarios, where progressively the market share of electrified powertrains in 2050 is increased. The sensitivity analysis carried out rises the presence of HEV, PHEV and BEV by a factor of 3, from worst to best case scenario.

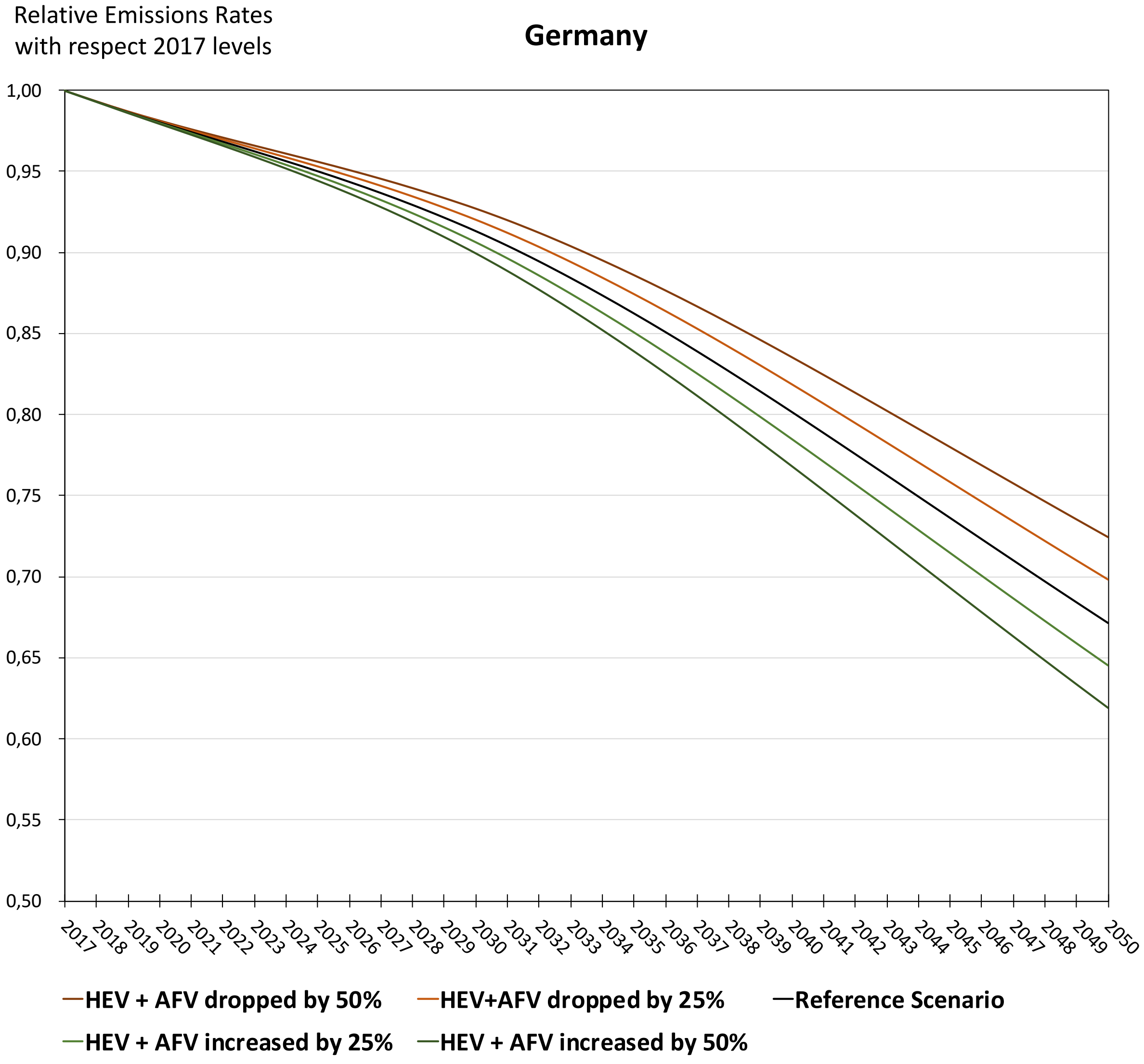

Figure 30: Normalized evolution of the GHG emissions rates for German LDV fleet.

Curves are expressed as the ratio of the GHG emissions rate year by year with respect 2017 levels.

These normalized results show the sensitivity of introducing more electrified powertrains into the fleet, while keeping the initial ratios constant. The spread of the GHG emissions reductions by 2050 for the German LDV fleet, shifts from a 28% reduction in the most conservative scenario, up to a 38% in the most optimistic, relative to 2017 levels. In order to more precisely display the impact of reaching higher non-conventional ICEV market penetrations, the following figure shows the percentage changes in GHG emissions rates over time, relative to the reference scenario.

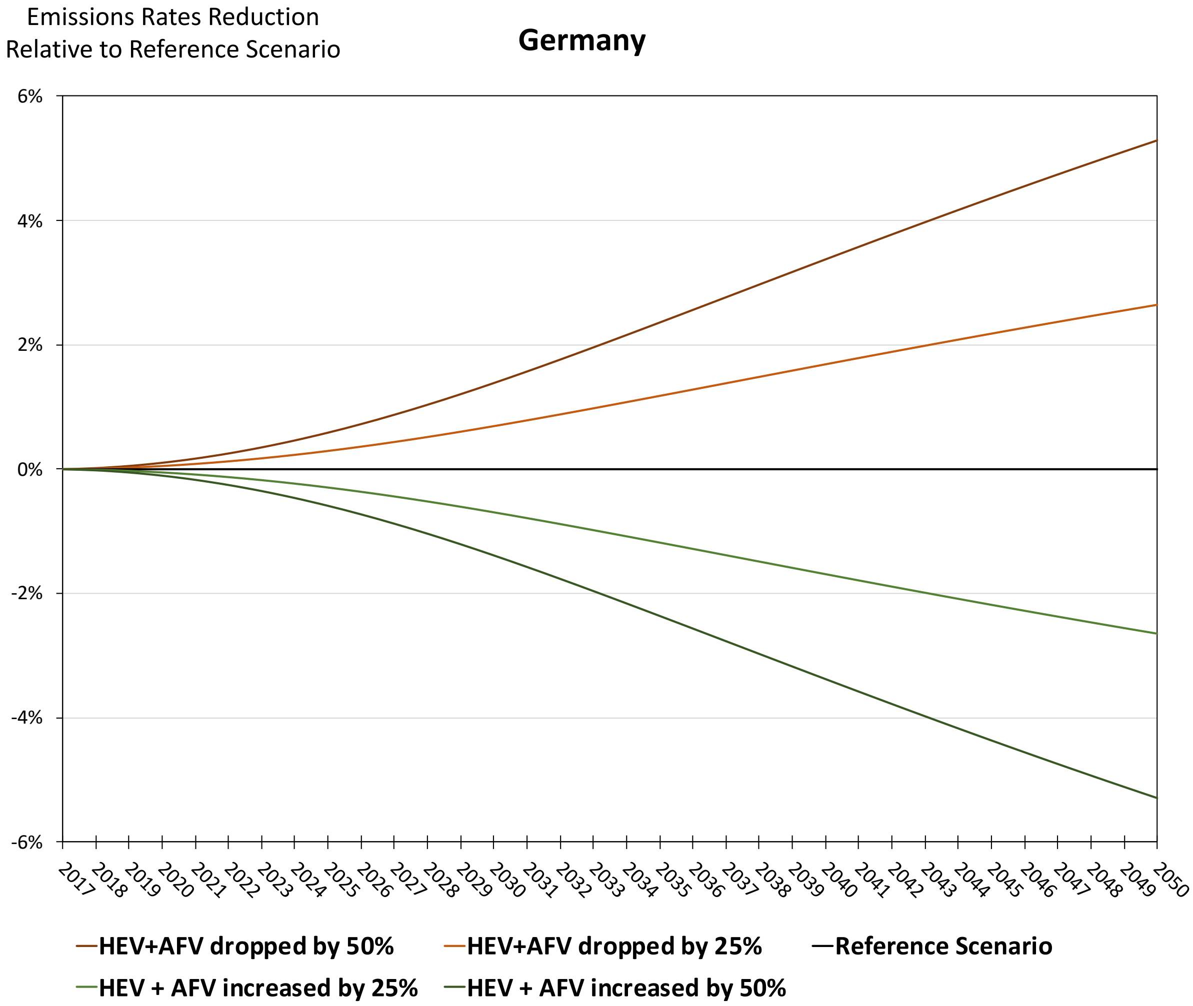

Figure 31: Total LDV fleet GHG emissions rates percentual differences with respect Reference Scenario in Germany for Sensitivity analysis results of electrified powertrains market penetration variations in 2050.

As can be seen, the overall spread can reach up to around 10% in 2050 for full range of scenarios for the German in-use fleet. This comparison accounts for the effect of increasing the share of HEV and AFV only, and keeps the ratios between powertrains constant.

Likely situations can be found for the rest of European countries, where the starting level of adoption of PHEV and BEV matter, as their importance is maintained after sustaining higher adoption rates for plug-in electric vehicles. Similar spreads are found in France and UK. Whereas for Netherlands and Spain the effects are more modest, as HEV predominate the sum of electrified powertrains market share. All results are presented at 2050 perspective.

Table 16: Comparison of the 2050 LDV fleet GHG emission rates in major European countries. Results for HEV + AFV market penetrations sensitivity analysis.

All ratios use 2017 levels as baseline.

Scenario	HEV + AFV dropped by 50%	HEV + AFV dropped by 25%	Reference Scenario	HEV + AFV increased by 25%	HEV + AFV increased by 50%
France	0,706	0,686	0,666	0,647	0,627
Germany	0,725	0,698	0,672	0,645	0,619
Netherlands	0,662	0,646	0,630	0,614	0,597
Norway*	0,852	0,823	0,780	0,747	0,709
Spain	0,643	0,631	0,619	0,606	0,594
United Kingdom	0,782	0,757	0,732	0,708	0,683

**** Special case as Norway's Reference HEV + AFV adoption scenario is chosen to be 100%, as the AFV adoption is already at an advanced stage by 2017.***

It can be inferred from table 15, that there are significant differences between some countries. Under the assumptions developed for the Fleet Model, the parc size scales according to population growth in some European countries LDV yearly sales are going to decrease, for example Spain or Netherlands. While other country's markets are expected to keep growing at quite significant rates, like UK or Norway. Thus, some countries have more advantageous conditions to reduce their road transportation environmental impact, depending on whether their in-use fleet size is growing or declining.

III – Emphasis on Fuel Consumption Reduction - Results

The emphasis on fuel consumption shows the effects of improving the efficiency of vehicle powertrain and vehicle technologies. It has very direct impact since appropriate improvements are applied to all new registrations in each LDV fleet. In this sensitivity analysis, the sales penetrations through 2050 remain as in the reference scenario. Only the fuel consumption improvement rates change.

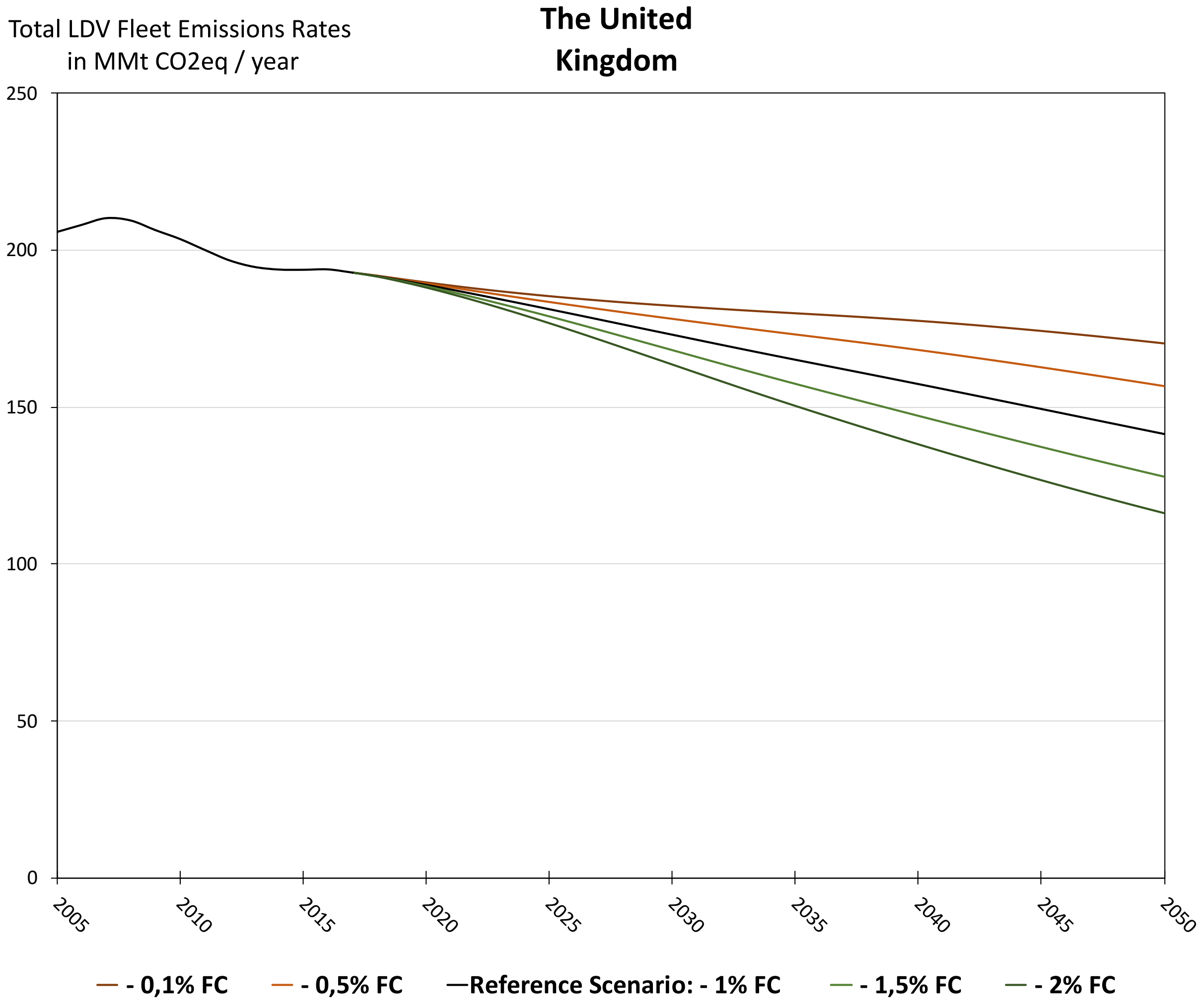

Figure 32: Total LDV fleet GHG emission rates for the United Kingdom. Sensitivity analysis results for yearly fuel consumption improvement rates variations.

In Reference Scenario, the improvement rate is set at -1%.

The results are important, since implementing a vehicle fuel efficiency improvement strategy has significant impact. The spread of this sensitivity analysis is similar for the six countries studied, yet less so far for Norway. This highlights the importance of encouraging efforts to reduce fuel consumption from new vehicles entering the in-use fleet. The potential in improving the fuel economy does vary from one country to another, as some have made larger progress in that particular aspect. Vehicle emissions policies in Europe and high fuel prices have already pushed to embrace this tendency. More detailed results about each country's emissions reduction ratios are given in Table 17.

Table 17: Comparison of the 2050 LDV fleet GHG emission rates in major European countries. Results for fuel consumption improvement rates sensitivity analysis.

All ratios use 2017 levels as baseline.

Scenario	Very low emphasis on FC reduction	Low emphasis in FC reduction	Reference Scenario - Average emphasis in FC reduction	High emphasis in FC reduction	Very High emphasis in FC reduction
France	0,799	0,736	0,666	0,605	0,551
Germany	0,804	0,741	0,672	0,611	0,557
Netherlands	0,750	0,693	0,630	0,573	0,523
Norway	0,816	0,765	0,709	0,658	0,614
Spain	0,745	0,685	0,619	0,560	0,509
United Kingdom	0,883	0,881	0,732	0,663	0,602

As is shown in Table 17, the range between a very low and very high emphasis in FC reduction leads to significant different results, in terms of GHG emissions. Between both situations, the spread goes from 20% additional emissions reductions for Norway, up to 28% in the case of United

Kingdom. Due to the fact that some countries have higher 2017 average fleet fuel consumption, potential for improving vehicle fuel efficiency is greater, hence with the same relative improvement rates, the absolute reduction is larger.

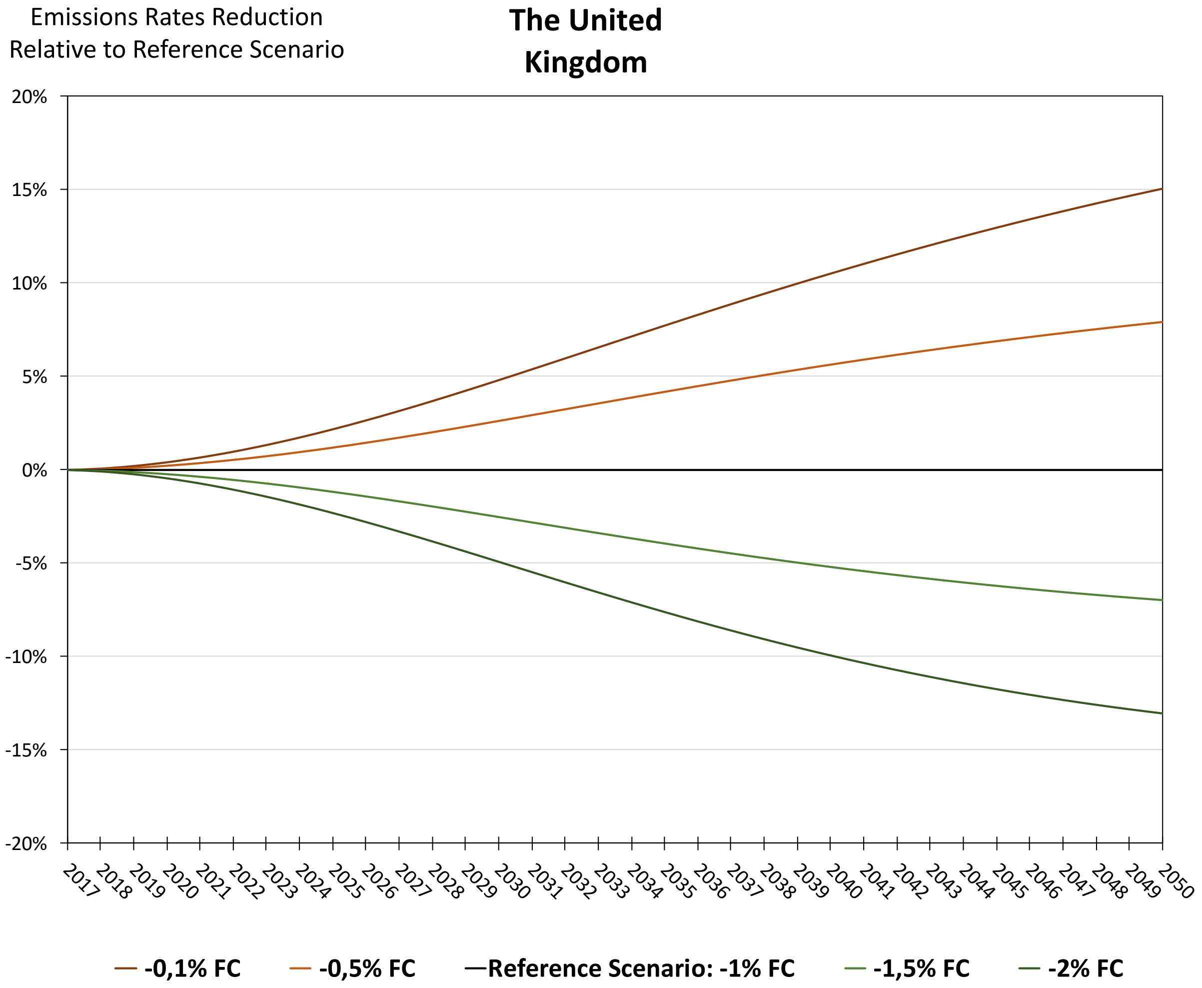

Figure 33: Total LDV fleet GHG emissions rates percentual differences with respect Reference Scenario in the United Kingdom for sensitivity analysis results of fuel consumption improvement rates variations.

In the figure above, the spread relative to the reference scenario is shown, as vehicle fuel consumption is varied, for the United Kingdom LDV fleet. With same market penetrations, very significative differences are apparent.

IV – AFV over HEV ratio variations – Results

In this sensitivity analysis, the objective is to keep the HEV and AFV cumulative market penetration in 2050 at 55% of the total, and to progressively change the $\frac{AFV}{HEV}$ ratio.

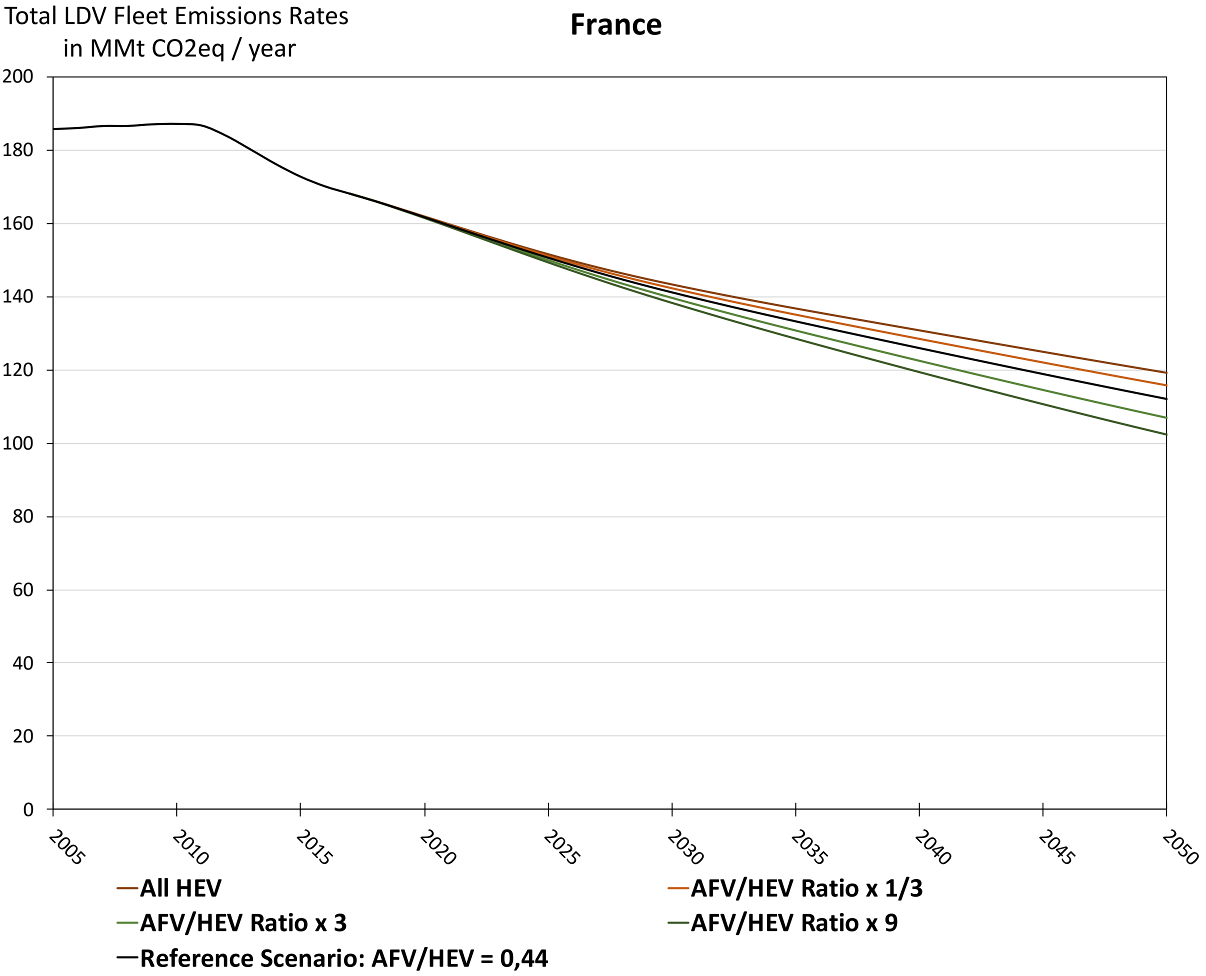

Figure 34: Total LDV fleet GHG emission rates for the France. Sensitivity analysis results for $\frac{AFV}{HEV}$ ratio variations.

Figure 34 shows this sensitivity analysis conducted for France and how the spread in this factor affects total GHG emissions. For the reference scenario in France, the HEV share becomes predominance by reaching 38%. The results show that replacing part of this market share with more BEV and PHEV registrations produces a moderate benefit. Also, as the market share of rechargeable vehicles grows larger than the HEV one, the consequences of giving priority to the adoption of plug-in electric vehicles has useful positive effects. The relevancy of this remark is underlined in the case of Norway, where BEV and PHEV are predominant over HEV. Shifting towards regular hybrid vehicles would imply a worse environmental impact from the Norwegian LDV in-use fleet.

Table 18: Comparison of the 2050 LDV fleet GHG emission rates in major European countries. Results for $\frac{AFV}{HEV}$ ratio sensitivity analysis.

All ratios use 2017 levels as baseline.

Scenario	Very high HEV adoption All electrified powertrains HEV	High HEV adoption	Reference Scenario - Current $\frac{AFV}{HEV}$ Ratio	High AFV adoption	Very High AFV adoption
France	0,708	0,688	0,666	0,635	0,608
Germany	0,734	0,703	0,672	0,641	0,622
Netherlands	0,658	0,646	0,630	0,615	0,596
Norway	0,934	0,800	0,709	0,670	0,654
Spain	0,634	0,628	0,619	0,603	0,577
United Kingdom	0,786	0,762	0,732	0,701	0,679

Replacing HEV by AFV has a useful environment benefit, meeting in some cases almost 6% of reductions with regard to the reference scenario. These effects would be more significant with larger market penetration for electrified powertrains, resulting in greater GHG emissions reductions.

V - BEV over PHEV ratio variations – Results

To compare the environmental impacts of giving priority to either BEV or to PHEV powertrain technologies is the scope of sensitivity analysis conducted in this section. In each of the six countries, the starting ratio of $\frac{BEV}{PHEV}$ indicates which AFV is more likely to be introduced in the market. This is taken into account while building each country's reference scenario, as the ratio in 2017 is kept. However, changes in this proportion will lead to different results in terms of fleet GHG emissions. For conducting this sensitivity analysis, it seems appropriate to set as baseline the "High AFV adoption scenario", where the cumulative non-ICEV (PHEVs and BEVs) market penetration in 2050 remains 55% but with a larger representation of AFV. This is necessary in order to develop a more useful understanding of the impacts that changing this ratio entail. For sure, the results would be amplified as the AFV market share becomes even more important, as it can be shown in the case for Norway.

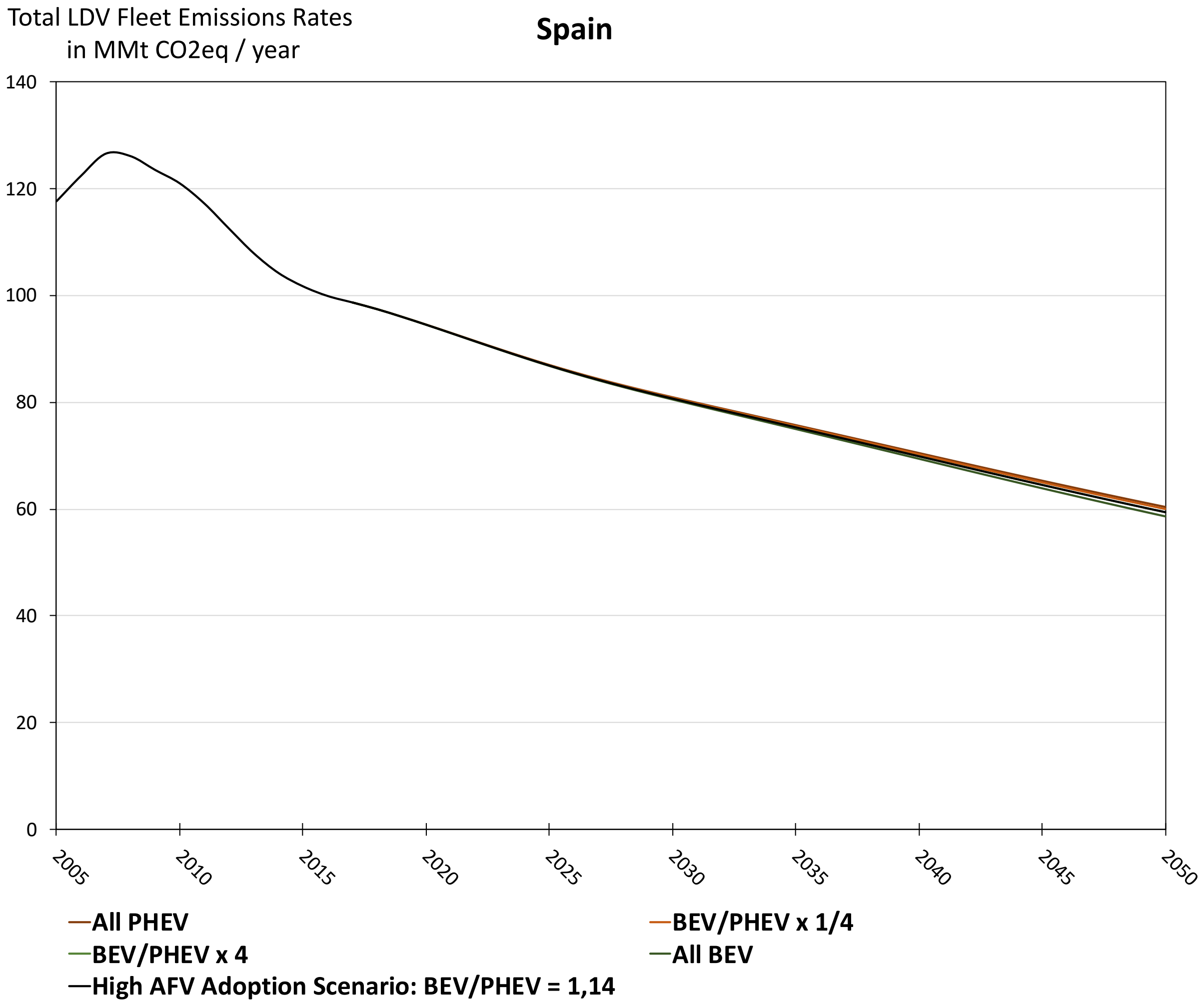

Figure 35: Total LDV fleet GHG emission rates for the Spain. Sensitivity analysis results for $\frac{BEV}{PHEV}$ *ratio variations.*

Figure 35 shows the results of the sensitivity analysis in the case of Spain, where AFV adoption remains still modest, with a 15% sales penetration in 2050.

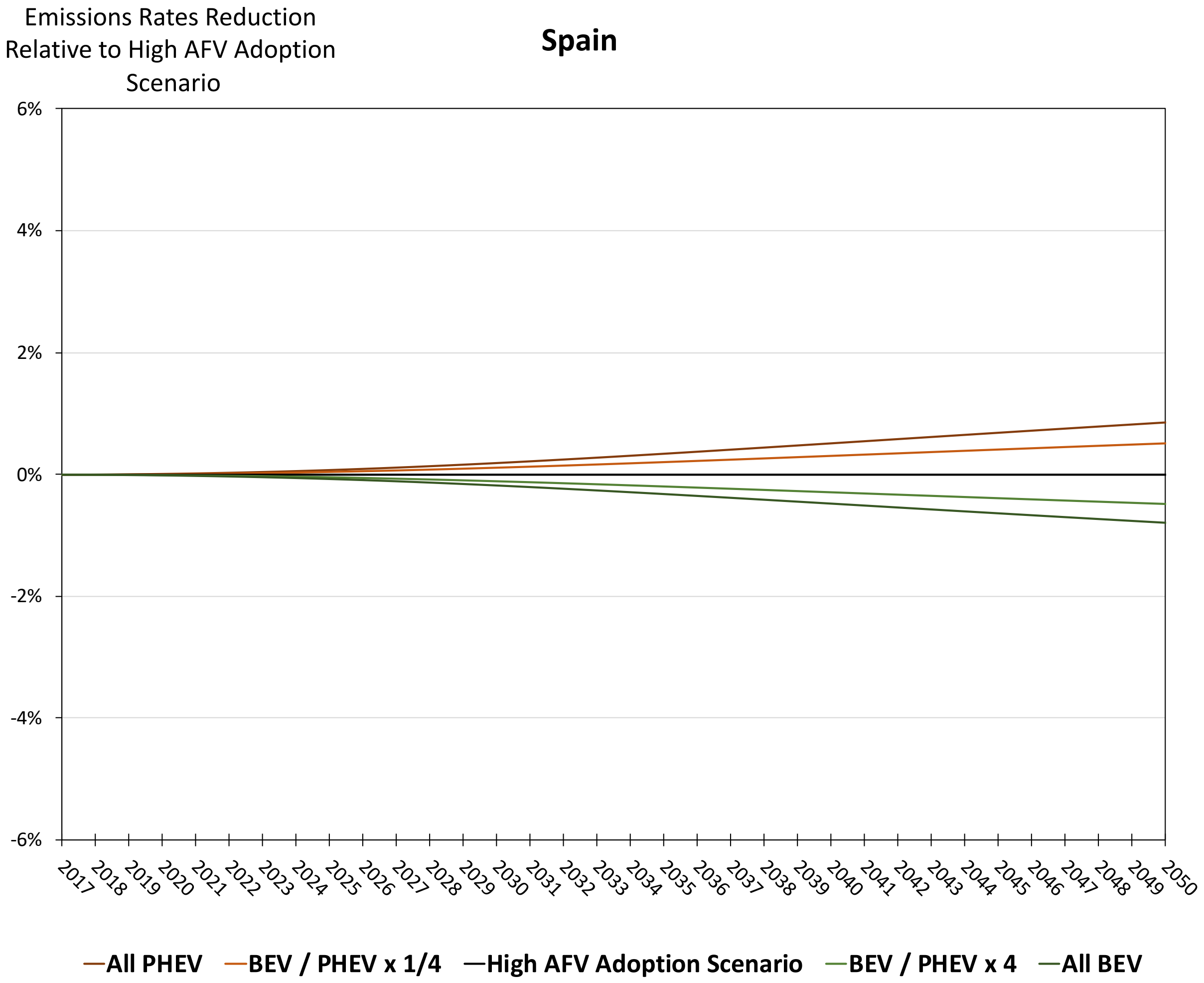

Figure 36: Total LDV fleet GHG emissions rates percentual differences with respect High AFV Adoption Scenario in Spain for sensitivity analysis results of $\frac{BEV}{PHEV}$ *ratio variations.*

Taking a closer look at the spread of the sensitivity analysis it can be inferred that higher rates of adoption of these greener powertrain technologies are needed to have a more significant impact of changing from all PHEV to all BEV. Other countries where the AFV market share in the studied scenario has more relevance reach spreads of almost 5%, as it can be entailed from the next table.

Table 19: Comparison of the 2050 LDV fleet GHG emission rates in major European countries. Results for $\frac{BEV}{PHEV}$ ratio sensitivity analysis.

All ratios use 2017 levels as baseline.

Scenario	Very high PHEV	High PHEV success	High AFV adoption scenario - Current $\frac{BEV}{PHEV}$ Ratio	High BEV success	Very high BEV success
France	0,657	0,645	0,635	0,628	0,624
Germany	0,660	0,653	0,641	0,627	0,617
Netherlands	0,623	0,615	0,611	0,609	0,608
Norway	0,753	0,709	0,670	0,635	0,612
Spain	0,611	0,608	0,603	0,598	0,595
United Kingdom	0,715	0,710	0,701	0,687	0,670

Countries where PHEV have had more success obtain more potential benefits from changing towards more extensive BEV adoption. The opposite is observed, as countries with high market penetration rates encounter a larger negative effect while adopting more PHEV.

VI – Segment size adoption market shares – Results

The vehicle segment sales sensitivity analysis is based on the adoption trends. Applying the normalized curves to each of the studied LDV fleets, different success trends can be extrapolated. As each of the countries sustain the rates of adoption of larger vehicles, this leads to different impacts depending on the case and scenario.

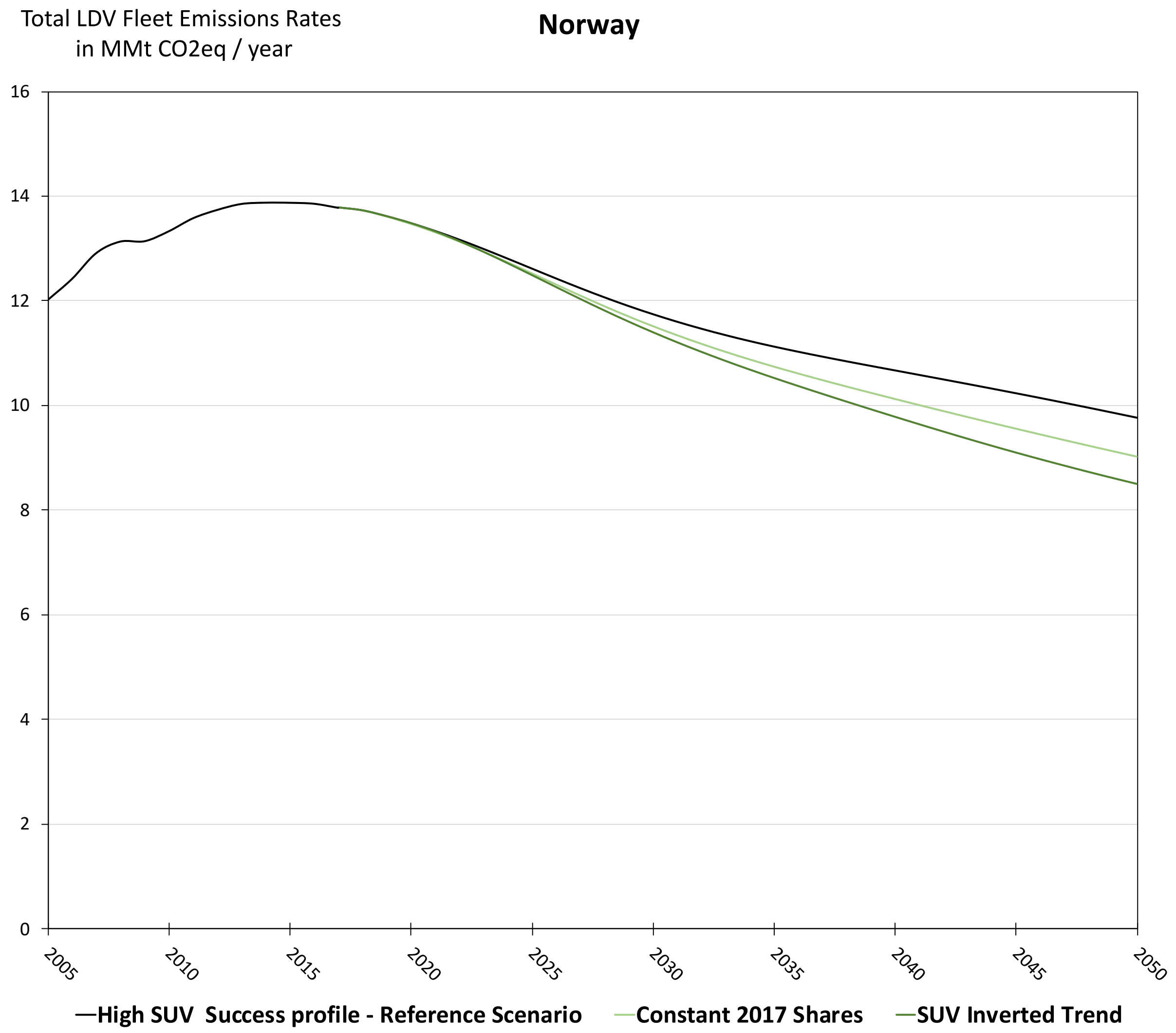

Figure 37: Total LDV fleet GHG emission rates for Norway. Sensitivity analysis results for different trends in vehicle segment size adoption.

For Norway, where in the "High SUV Success Trend" scenario SUV follow the trend and reach almost 64% segment market share by 2050. This is a large progression, corresponding to a significant shift of consumers behavioral preferences. Germany and the United Kingdom have a similar situation. Since increasing SUV adoption is well embraced. Nonetheless, countries like France, Netherlands or Spain experience less impact as SUV are less popular. In these later cases, the sensitivity analysis changes the total LDV fleet GHG emissions by 1%, and smaller still for Spain and Netherlands. Whereas in Norway potential benefits reach almost a 10% reduction while adopting smaller vehicle segment for their new passenger cars registrations.

Table 20: Comparison of the 2050 LDV fleet GHG emission rates in major European countries. Results for vehicle segment size adoption sensitivity analysis.

All ratios use 2017 levels as baseline.

Scenario	High SUV success trend	Constant 2017 shares	SUV inverted trend
France	0,666	0,656	0,653
Germany	0,672	0,650	0,644
Netherlands	0,630	0,625	0,624
Norway	0,709	0,655	0,616
Spain	0,619	0,614	0,613
United Kingdom	0,732	0,710	0,703

Table 20 gathers all the six countries' GHG emissions rate, 2050 relative to 2017, spreads regarding the Car and SUV segment sensitivity analysis for the major European countries studied.

VII – Electricity grid improvement – Results

The last sensitivity analysis performed in this research evaluates the effects of recharging the plug-in electric vehicles greener electricity generation grids. As electrified vehicles become more important, the effects of transforming a greener electricity grid would be expected to reduce GHG emissions from the LDV fleets. These calculations were made for the high AFV adoption case, by changing the evolution trends of the electricity generation grid. This is applied to each country, starting with the current grid and extrapolating, to continue the progress achieved so far.

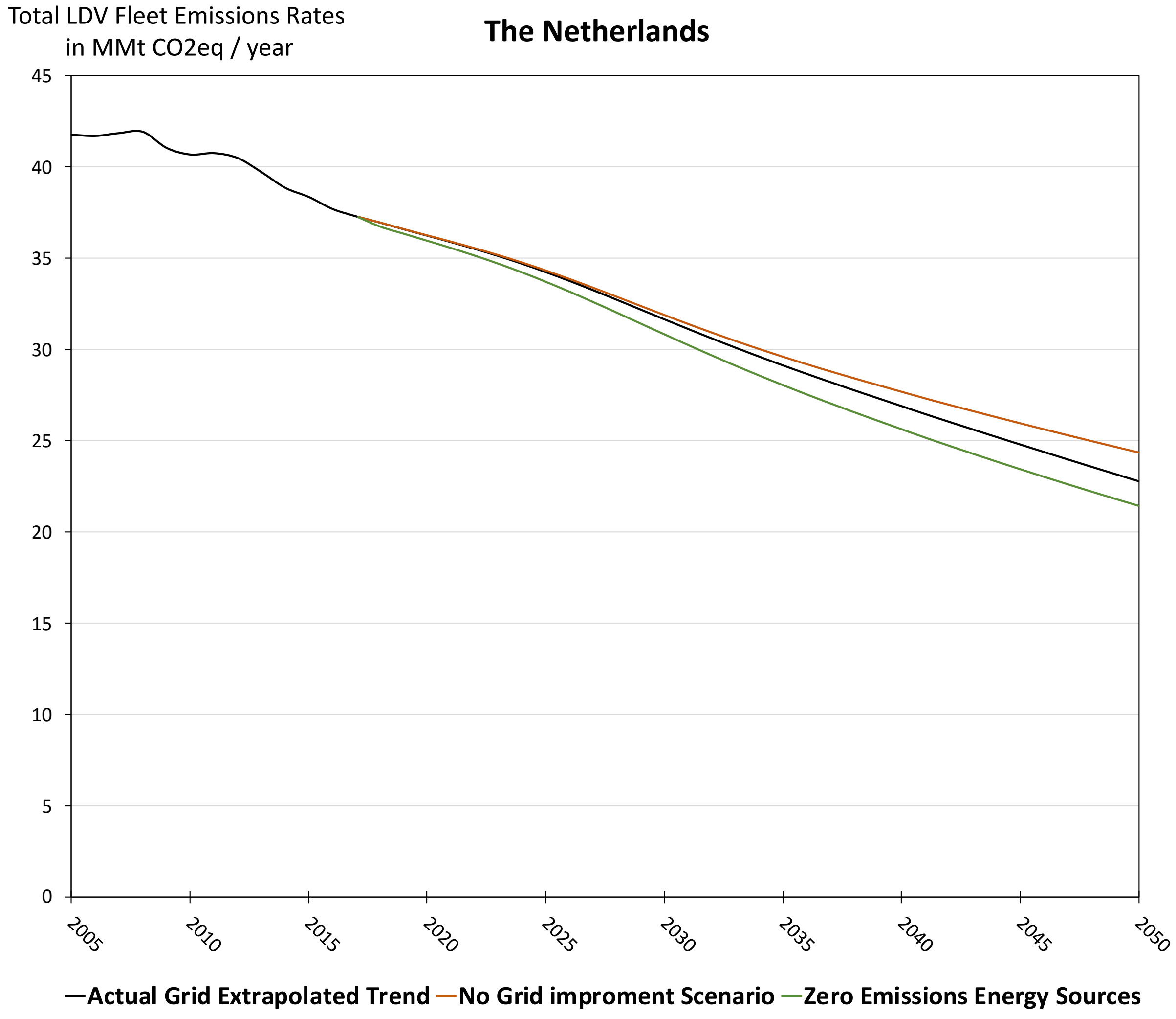

Figure 38: Total LDV fleet GHG emission rates for the Netherlands. Sensitivity analysis results for different electricity grid improvement trends.

The Netherlands is a country where the benefits of recharging EV with greener energy might be expected to have a considerable impact. Plug-in electric vehicle adoption has spread remarkably, and the electricity grid still includes significant fossil fuel energy sources.

Other countries obtain little benefit from expanding the presence of renewable energies in the electricity production process, as some countries already have green generating grids or still do not reach high enough number of rechargeable vehicles in their in-use fleet for the charging grid impact to yet be meaningful. For instance, France or Norway which represent the countries with the cleanest grids among those studied, the effect of improving the grid's carbon intensities is very modest.

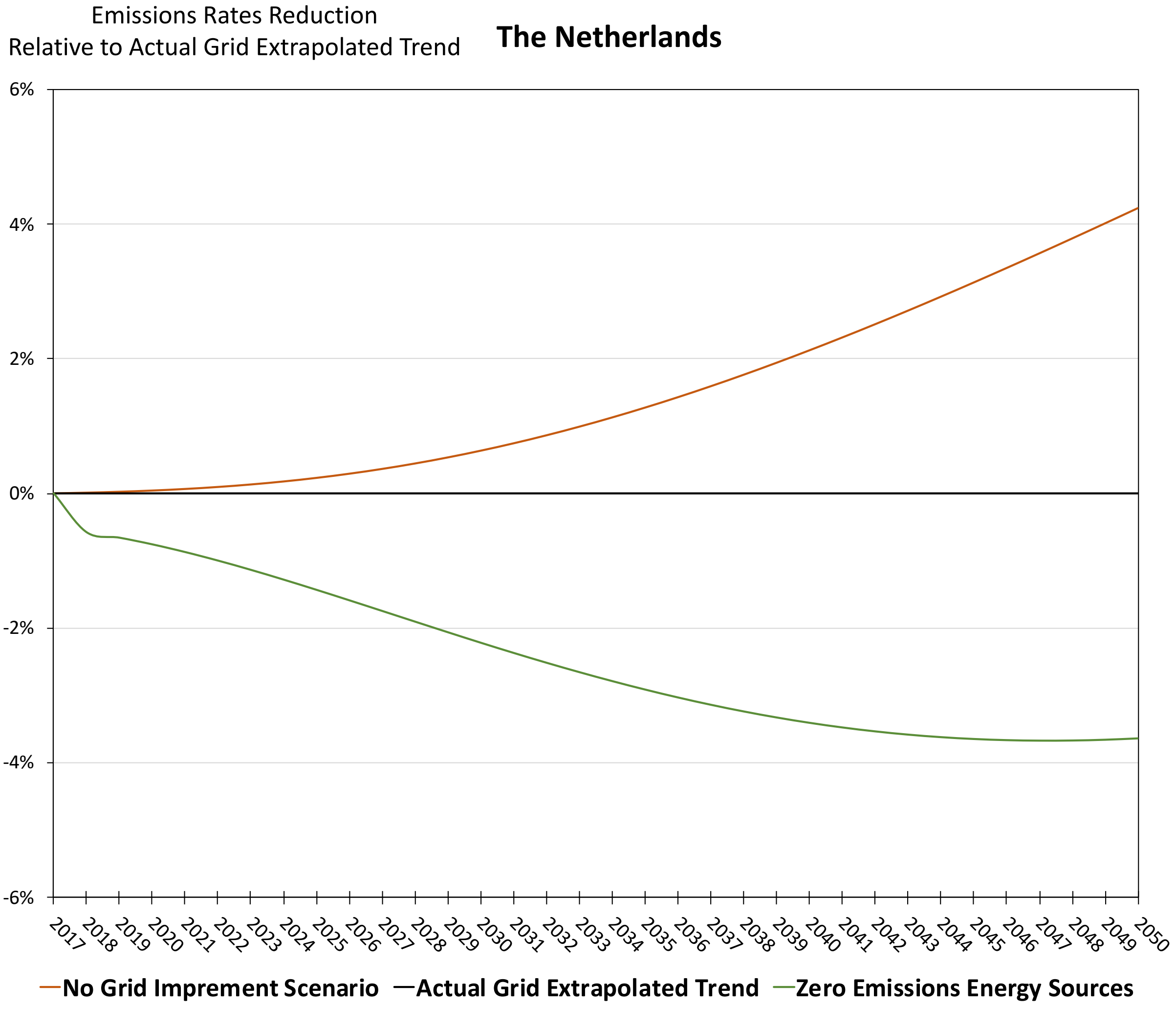

Figure 39: Total LDV fleet GHG emissions rates percentual differences with respect Actual Grid Extrapolated Trend in the Netherlands for sensitivity analysis results of electricity grid improvements.

The GHG emissions spread for the Dutch LDV fleet, of having a less green or zero emissions grid, results an 8% reduction in 2050. A similar situation occurs in Germany, where the grid is still "dirty" and nuclear energy will disappear in the next decade approximately. However, France and Norway barely reach 1% benefits, followed by Spain which is closer to the 2%. For the United Kingdom the range is some way in between having 4% reductions in total LDV GHG emissions.

Table 21: Comparison of the 2050 LDV fleet GHG emission rates in major European countries. Results for electricity grid improvements sensitivity analysis.

All ratios use 2017 levels as baseline

Scenario	No Grid improvement scenario	Current Grid extrapolation High AFV adoptions	Zero Emissions Energy Sources
France	0,644	0,635	0,633
Germany	0,714	0,641	0,633
Netherlands	0,653	0,611	0,575
Norway	0,677	0,670	0,665
Spain	0,619	0,603	0,600
United Kingdom	0,736	0,701	0,697

In major European countries where electricity grids are relatively clean, and future trends will continue the previous efforts to reduce emissions, it is clear that the sensitivity analysis highlights that the efforts should aim first and foremost in getting more electrified powertrain vehicles on the road.

The additional reductions in the transportation sector's emissions achieved through continuing to clean up the electricity generating grid are relatively modest. However, the total amount of electricity used in these countries is much larger than the amount of electricity used for recharging the PHEV and BEV on the road, which for sure will have a substantial environmental impact for other sectors contributing to global warming. The impact of continuing to clean up the grid on any countries overall GHG emissions is much more significant and important than the relative portion accounted to road transportation sector. Going further, in future situations where plug-in electric vehicles could experience wider shares of the in-use vehicles, the effect of having a greener electricity generating grid would be amplified.

Chapter 7 – Findings and conclusions

European Light-Duty Vehicle fleets continue to be dominated by combustion engine vehicles. Among all powertrain technologies available, Alternative Fuel Vehicles are still in their early stages of deployment. This thesis describes the fundamental challenges that electrified vehicles need to overcome to achieve successful adoption. The six European countries studied are chosen as being most representatives for different stages and strategies for introducing new powertrain technologies into the in-use fleet. The incentives are adopted attempting to reduce the gap between conventional vehicles and promising plug-in electric vehicles. Although meaningful advances have been made in recent years from the technology and infrastructure perspective, additional progress is needed to assure similar overall convenience to traditional personal means of transport. Consumer perception remains a key area where efforts must be intensified to achieve faster adoption of newer powertrains adoption. The ultimate goal of replacing fossil fuel vehicles by electrified powertrains is to mitigate the environmental impact of the road transportation sector and limit current energy dependence on petroleum. Using Life-Cycle Assessment information it is possible to obtain robust estimates of total GHG emissions for each powertrain technology over its full useful life. In this thesis, emissions resulting from the vehicle manufacturing process, and the fuel - or energy - supply and production are considered. This provides a more complete evaluation for each existing alternative when comparing their real environmental consequences.

Limiting the greenhouse gas emissions is crucial to reduce harmful global warming effects and to control the excessive rise of ambient temperatures. In that sense, this research develops a set of strategies which cover the range of possibilities for reducing Light-Duty Vehicles' carbon footprint. The actions are divided between improving the fuel-efficiency of actual technologies, adopting behavioral changes whose cumulative effect provides a substantial benefit or transforming actual means of transport towards greener technologies. Acknowledging all possible paths leading to a less emitting Light-Duty fleets is the first step in estimating their cumulative potential impact.

Based on an assessment of all actions likely to lower GHG emissions, a range of foreseeable scenarios are envisaged to analyze the effects of implementing different strategies. By using a simulation tool to run in-use vehicle fleet calculations, this thesis estimates likely future scenarios impacts. This is utilized to quantify the environmental consequences of accomplishing a set of actions. However, projecting situations always entails some uncertainty, all calculations are dependent on assumptions. Nevertheless, our hypotheses are thoughtfully established and by comparing consequences, the uncertainty is less significant since all calculations are done following a similar praxis.

The Fleet Model is the simulation tool utilized and adapted in this thesis to explore several prospective situations. The development of this methodology allows us to ground and integrate all the information and data required to estimate Light-Duty Vehicle total fleet greenhouse gas emissions. Incorporating the vehicle sales profiles for each of the studied countries, complemented by vehicle segment and powertrain technology shares, as well as accounting for their performance characteristics, allows us to apply a common modeling for each approach of the calculations. This allows to use data-based starting situations in each case, from which future development can be extrapolated. Including the electricity generation mix in each country defines their respective electricity supply profile. Assigning the carbon intensities to each source of energy allows us to estimate the grid's influence on road transportation greenhouse gas emissions while recharging plug-in electric vehicles. The richness of detail incorporates the differences between each of the major European countries analyzed in this thesis.

Multiple scenarios explore the consequences of using different values of key parameters through comparing the results from different sets of scenarios. Shifting from a plausible, well-founded, yet uncertain reference scenario we are able to estimate the effects in terms of greenhouse gas emissions, due to variations in influencing factors would have. Across a given range, sensitivity analyses are performed to assess the changes in environmental impacts resulting from different strategies. Throughout this thesis work, sensitivity analyses cover changes in consumer preferences in buying a particular vehicle segment, the powertrain technology market penetrations reached over future time horizons or the vehicle's performance evolution. Different energy generation mix possibilities are also considered for each country analyzed.

The results show the evolution year by year of total Light-Duty Vehicle fleet GHG emissions out to 2050. The spread between different scenarios within each sensitivity analysis reflects how significant the parameter studied is. Some results display a wider spread implying a bigger impact when modifying the analyzed actions among the boundaries assumed. Other simulations show more modest reductions, highlighting the relative importance of strategies analyzed when aiming to decrease total Light-Duty Vehicles greenhouse gas emissions. The calculations analyze also the effectiveness of a given strategy specifically for each of the six European countries studied. The interest of this thesis lies in characterizing the various stages of AFV adoption encountered over different LDV in-use fleets and give rigorous assessment in each case of the potential benefits of attaining a set of reasonable situation.

Key findings from the research:

1) A population weighted average of every country's reference scenario carried out in this thesis, the LDV in-use fleet benefits from adopting electrified powertrains represents about one third reduction in total GHG emissions, rate in 2050 from the 2017 value.

2) For the major European countries studied, transforming the current in-use car parc so it has a significantly greater presence of EVs is seen to be a promising strategy to mitigate the climate change contributions from the transportation sector. On average, an additional 10% GHG emissions reduction in 2050 can be achieved through increasing by a factor of 3 the AFV penetration rates, during the 2017-2050 period.

3) Based on extrapolating current rates of adoption suggest that this needs to be considered as a longer-term strategy, as the number of plug-in electric vehicles in-use needs to be much higher than it is currently. Almost a ten-year lag is observed between the market penetration rates and their actual share in the in-use composition. This delay needs to be incorporated into our strategic thinking in order to understand the real effects of AFV adoption.

4) Improvements in ICEV and HEV fuel consumption remain an important strategy to mitigate negative environmental consequences from LDV fleets. They have very significant direct effects that can be implemented near term to each vehicle segment and powertrain technology. Allocating resources now towards developing more fuel-efficient mainstream vehicles proves to have a significant reducing impact in total GHG emissions. By implementing aggressive yet realistic trends for fuel consumption reduction, it allows lowering an average additional one-quarter the total GHG emissions rate from the in-use vehicle fleets by 2050.

5) The progressive market adoption of vehicles with greater size and larger weights has negative environmental consequences, the overall potential for reducing GHG emissions. Consumer preferences regarding vehicle segmentation, and its adoption, differ from one country to another. However, for those LDV markets experiencing a significant increase in the numbers of larger vehicles purchased i-e-, with substantial SUV market penetration rates, would potentially obtain an 8% GHG emissions benefit from reversing the trend.

6) Regarding LDV fleet emissions from plug-in electric vehicles, the electricity grid is responsible for supplying the necessary energy to recharge these vehicles. Therefore, the impact of having a grid less dependent on fossil fuel energy sources has a significant effect on the total fleet GHG emissions outcome. For European countries like France, Norway or even Spain and the United Kingdom which already have greener electricity generation grids, the result of further greening the electricity supply sources is less significant, having only about on-average a 2% benefit in the scenarios simulated. In the case of Germany and Netherlands, which are more dependent on coal and natural gas as electrical energy sources, the results have a greater impact, potentially reducing total GHG emissions by 8% in 2050. Nevertheless, this effect will be enhanced as the in-use number of EVs grows to a significant share of the LDV fleet.

7) Major European countries have already reversed the trend where, year by year total GHG emissions associated with the road transportation sector progressively increased. Larger emissions reductions over the next couple of decades will be needed to attain our desired environmental goals. Reinforcing policies are suggested to encourage consumers to embrace the change towards more environmentally respectful habits. Currently, incentives are primarily targeted to promote BEV purchase and use. However, this thesis shows that other powertrain technologies such as HEV and PHEV have significant potential for comparable positive impacts in terms of GHG emissions.

8) Considering the rates of adoption assumed in scenario calculations, PHEVs GHG impact is closely comparable to that of an equivalent BEV. In this early stage of introducing electrified powertrains, both types of EVs provide considerable benefits with regard to conventional internal combustion engines, from the emissions point of view. This thesis results show that shifting from all PHEV to all BEV market penetrations by 2050 will imply a modest 3% total emissions reduction in average for most of major European countries. Note that Norway, a particular case where AFV are predicted to reach higher penetration into their in-use fleet by 2050, the GHG emissions impact is likely to be more significant, reaching almost a 15% LDV fleet emissions decrease.

9) Separately, the impact of each parameter analyzed might seem more modest than expected. However, they all represent benefits from the total transportations LDV fleet's GHG emissions and often are additive; it is their cumulative effect which offers broader reductions and must be targeted. All efforts should point in the same direction to more effectively reduce the negative environmental consequences of the road transportation sector, and to guarantee more BEVs as sustainable personal means of transportation.

References

[1] *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* - Figure 8.1, Chapter 8 - Sims R., R. Schaeffer, F. Creutzig, X. Cruz-Núñez, M. D'Agosto, D. Dimitriu, M.J. Figueroa Meza, L. Fulton, S. Kobayashi, O. Lah, A. McKinnon, P. Newman, M. Ouyang, J.J. Schauer, D. Sperling, and G. Tiwari - IPCC 2014 – [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)] - Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] *CO2 Emissions from Fuel Combustion Highlights (2018 edition)* - Figure 2 p.24 – International Energy Agency IEA 2018a.

[3] *CO2 Emissions from Fuel Combustion Highlights (2018 edition)* - Figure 20 p.15 – International Energy Agency IEA 2018b.

[4] *Greenhouse gas emissions from transport sector* - Fig.3: Share of transport greenhouse gas emissions - https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-11

[5] *BP Statistical Review 2019 68th edition* – Reserves to production (R/P) ratios p.15.

[6] "Gasoline versus Diesel: Comparing CO2 Emissions Levels of a Modern Medium Size Car Model Under Laboratory And On-Road Testing Conditions" – J. Dornoff and F. Rodríguez – The International Council on Clean Transportation ICCT 2019.

[7] *On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions* – I. B. Akerlind, P. Bastani, I. Berry, K. Bhatt, A. Chao, E. Chow, V. Karplus, D. Keith, M. Khusid, E. Nishimura, and S. Zoepf - Massachusetts Institute of Technology, Sloan Automotive Laboratory Engineering Systems Division 2015 - [J. B. Heywood and D. Mackenzie] - MIT Energy Initiative Report November 2015.

[8] "This latest milestone of 10 million units was achieved just nine months after total sales reached 9 million units at the end of April 2016" - Toyota City, Japan, 14 February 2017 - https://newsroom.toyota.eu/global-sales-of-toyota-hybrids-reach-10-million/

[9] "Plug-in hybrid" - From Wikipedia, the free encyclopedia - https://en.wikipedia.org/wiki/Plug-in_hybrid

[10] "Looking Back to Electric Cars" – Massimo Guarnieri, Member IEEE - Dipartimento di Ingegneria Industriale - Università di Padova, via 8 Febbraio, 2 – 35122 Padova.

[11] "Electric Car Evolution" – Zachary Shaham – Clean Technica 26 April 2015.

[12] *Fuel Cell Technology Handbook* – CRC Press 2003 by Taylor & Francis Group, LLC – [Greg Hoodgers].

[13] "Developing hydrogen fueling infrastructure for fuel cell vehicles: A status update" – A. Isentadt and N. Lutsey – The International Council on Clean Transportation ICCT 2017

[14] "N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels" - P. J. Crutzen, A. R. Mosier, K. A. Smith, and W. Winiwarter - Atmospheric Chemistry and Physics 2008.

[15] “Alternative Fuel Vehicle Data: Definitions, Sources and Explanatory Notes” – U.S. Energy Departement Information Administration 2017.

[16] *EV Outlook 2019 report* - sources IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019); CAAM (2019) – Figure 1.1 p.33 - International Energy Agency IEA 2019.

[17] “Global Sales December & 2018: 2 Million Plug-In Electric Cars Sold” – M. Kane – 31 January 2019 – InsideEVs - https://insideevs.com/news/342547/global-sales-december-2018-2-million-plug-in-electric-cars-sold/

[18] *EV Outlook 2019 report* - sources IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019); CAAM (2019) – International Energy Agency IEA 2019.

[19] “Global Light Vehicle Sales Update” – LMC December 2018 Summary - https://lmc-auto.com/wp-content/uploads/2019/01/LMCA-Global-Light-Vehicle-Sales-Update-December-2018.pdf

[20] *EV Outlook 2019 report* - sources IEA analysis based on country submissions, complemented by ACEA (2019); EAFO (2019); EV Volumes (2019); Marklines (2019); OICA (2019); CAAM (2019) - International Energy Agency IEA 2019.

[21] *EV Outlook 2018 report* - sources IEA analysis based on country submissions, complemented by ACEA (2018); EAFO (2018); EV Volumes (2018); Marklines (2018); OICA (2018) – International Energy Agency IEA 2018.

[22] “Norway EV Market: The first quarter of 2019 more than half of the passenger car market in Norway was fully electric” - Norsk ebilforening - https://elbil.no/english/norwegian-ev-market/

[23] “Electric Cars: Why Little Norway Leads The World In EV Usage” – D. Nikel – Forbes 18 June 2019 - https://www.forbes.com/sites/davidnikel/2019/06/18/electric-cars-why-little-norway-leads-the-world-in-ev-usage/#7823446813e3

[24] “EV Tipping Point in Norway” – R. L. Hales - Clean Technica 18 August 2019.

[25] “Car Sales statistics based on Kraftfahrt-Busesamt data” - Pressemitteilungen 2019 Kraftfahrt-Busesamt KBA data - https://www.kba.de/DE/Presse/Pressemitteilungen/2019/2019_node.html

[26] “December EV Registrations 2018” - Electric & alternatively-fueled vehicles registrations SMMT News - https://www.smmt.co.uk/2019/01/december-ev-registrations-2/

[27] “Electric Car Market Statistics” – Next Green Car Market Statistics, sources DFT Vehicle Licensing - https://www.nextgreencar.com/electric-cars/statistics/

[28] “Baromètre annuel : près de 40 000 véhicules électriques immatriculés en France en 2018” – Avere France – 9 January 2019 - http://www.avere-france.org/Site/Article/?article_id=7532&from_espace_adherent=0

[29] “France to ban sales of petrol and diesel cars by 2040” – A. Chrisafis and A Vaughan – The Guardian 6 July 2017.

[30] “Registraties elektrische auto’s in 2018 verdrievoudigd” – Bovaj 4 January 2019 - https://mijn.bovag.nl/actueel/nieuws/2019/januari/registraties-elektrische-auto’s-in-2018-verdrievou

[31] “Spain Closes 2018 With Record Electric Car Sales In December” – M. Kane – 15 January 2019 InsideEVs - https://insideevs.com/news/341967/spain-closes-2018-with-record-electric-car-sales-in-december/

[32] “The Electric Car at the Beginning of 2019” – M. Merodio – 2 April 2019 – Magnus Commodities - https://www.magnuscmd.com/the-electric-car-at-this-beginning-of-2019/

[33] “WHITE PAPER – European Transport: Time to decide” - COM (2001) 370 final – European Commission - 12 September 2001.

[34] “GREEN PAPER: A 2030 framework for Climate and energy policies” – COM (2013) 169 final – European Commission 27 March 2013.

[35] “EU Action: Transport Emissions” – COM (2016) 501 - A European Strategy for Low-Emission Mobility - European Commission 2016 - https://ec.europa.eu/clima/policies/transport_en

[36] “Monitoring of CO2 emissions from passenger cars” - Regulation (EC) No 443/2009 - European Environmental Agency EEA – 2009.

[37] “Monitoring of CO2 emissions from vans” - Regulation (EC) No 551/2011 - European Environmental Agency EEA - 2011.

[38] *European Market Statistics Report 2018-2019 Pocket Book 2018/2019* - Fig 3-6 p.31: Passenger car emission by member state – The International Council for Clean Transportation ICCT 2019.

[39] “REGULATION (EC) No 715/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6)” – Reg 715/2007 – European Parliament.

[40] *European Market Statistics Report 2018-2019 Pocket Book 2018/2019* - Fig 3-10 p.33: Passenger car emission by member state – The International Council for Clean Transportation ICCT 2019.

[41] “Country Incentives in European Union and Enlarged Territory” – European Alternative Fuel Observatory EAFO 2019 - https://www.eafo.eu/countries/european-union/23640/incentives

[42] “Electric vehicle purchase incentives per country in Europe” – European Automobile Manufacturers Association ACEA statistics.

[43] “Bis zu 4.000 Euro Förderung für Elektroautos” – KFZ-betrieb – 17 April 2016 - https://archive.is/20160616183533/http://www.kfz-betrieb.vogel.de/wirtschaft/articles/531213/#selection-803.0-803.44

[44] “What are the incentives for buying an electric car?” – EV Box UK & Ireland - https://evbox.com/uk-en/learn/faq/incentives-buying-electriccar

[45] “Bonus-malus” - From Wikipedia, the free encyclopedia - https://en.wikipedia.org/wiki/Bonus-malus#French_taxation

[46] “Norwegian EV policy: Norway is leading the way for a transition to zero emission in transport” – Norsk ebilforening - https://elbil.no/english/norwegian-ev-policy/

[47] “Effectiveness of incentives on electric vehicle adoption in Norway” – A. C. Mersky, F. Sprei, C. Samaras and Z. Qian – *Transportation Research Part D* – 31 March 2016.

[48] “Rapidly falling costs of battery packs for electric vehicles” – B. Nykvist and M. Nilsson - Nature Climate Change volume 5, pages 329–332 (2015) – 23 March 2015.

[49] “Learning only buys you so much: Practical limits on battery price reduction” – I. Lisa, M. Sam, Y.Chiang and W. H. Greene – Applied Energy 239 (2019) 218-224 – 5 August 2018.

[50] "A Behind the Scenes Take on Lithium-ion Battery Prices" – L. Goldie-Scot – BloomberNEF – 5 March 2019 - https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

[51] "A review on the key issues of the lithium ion battery degradation among the whole life cycle" - X. Han, L. Lu, Y. Zheng, X. Feng, Z. Li, J. Li and M. Ouyang - eTransportation 1 (2019) 100005 – 3 July 2019.

[52] "An Overview of Costs for Vehicle Components, Fuels, Greenhouse Gas Emissions and Total Cost of Ownership" – R. Kochhan, S. Fuchs, B. Reuter, P. Burda, S. Matz and M. Lienkamp – 2017 Update authors: M. Fries, M. Kerler, S. Rohra, S. Schickram, M. Sinning and M. Lienkamp.

[53] "Impact of Vehicle Technologies Office Targets on Battery Requirements" - Figure 44 p.32 – ANL/ESD-16/22 – Energy Systems Division - Argonne National Laboratory ANL 2016 - https://www.autonomie.net/pdfs/ANL%20-%20Report%20ESD16-22%20-%20Impact%20of%20Vehicle%20Technologies%20Office%20Targets%20on%20Battery%20Requirements.pdf

[54] *EV Outlook 2019 report* – Table 2.2: Overview on the different EV charger characteristics p.66 - International Energy Agency IEA 2019.

[55] "Charging infrastructure for electric road vehicles 2018" - Table 2: Overview of charging modes and types p.20 - Research for TRAN Committee.

[56] "How EU Member States roll-out electric-mobility: Electric Charging Infrastructure in 2020 and beyond" – Executive Summary – Platform for Electromobility 2017.

[57] *EV Outlook 2019 report* – Charging infrastructure policies p.72 - International Energy Agency IEA 2019.

[58] "Car Companies Aren't Even Trying to Sell Electric Cars" – J.Dreaton - Thinking progress Nexus Media – 15 January 2019 - https://thinkprogress.org/car-companies-are-not-promoting-selling-electric-vehicles-854eb5ea496a/

[59] "The future is electric, but why's it taking so long?" – N. Lutsey - The International Council for Clean Transportation ICCT 2019.

[60] "Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration" – F. Mwasilu, J. J. Justo, E. Kim, T. D. Do and J. Jung – Renewable and Sustainable Energy Reviews Volume 34, June 2014, pages 501-516 – June 2014

[61] *EN ISO 14040 (2006): Environmental management – Life cycle assessment – Principles and framework*

[62] *Spatiotemporal Lifecycle Assessment of the Light-Duty Vehicle Fleet of United States* – Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy at the Massachusetts Institute of Technology – Department of Mechanical Engineering – 30 July 2018.

[63] "Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions" – Table 1 - The International Council for Clean Transportation ICCT 2018.

[64] *On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions* – Figure 9.29 p.199 - I. B. Akerlind, P. Bastani, I. Berry, K. Bhatt, A. Chao, E. Chow, V. Karplus, D. Keith, M. Khusid, E. Nishimura, and S. Zoepf - Massachusetts Institute of Technology, Sloan Automotive Laboratory Engineering Systems Division 2015 - [J. B. Heywood and D. Mackenzie] - MIT Energy Initiative Report November 2015.

[65] "Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions" – Figure 1 - The International Council for Clean Transportation ICCT 2018.

[66] *Spatiotemporal Lifecycle Assessment of the Light-Duty Vehicle Fleet of United States* – D. Wu - Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy at the Massachusetts Institute of Technology – Department of Mechanical Engineering – 30 July 2018.

[67] *On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions* – Table 3.2 p.24 - I. B. Akerlind, P. Bastani, I. Berry, K. Bhatt, A. Chao, E. Chow, V. Karplus, D. Keith, M. Khusid, E. Nishimura, and S. Zoepf - Massachusetts Institute of Technology, Sloan Automotive Laboratory Engineering Systems Division 2015 - [J. B. Heywood and D. Mackenzie] - MIT Energy Initiative Report November 2015.

[68] *Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S.* – L. W. Cheah - Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy at the Massachusetts Institute of Technology Thesis Report.

[69] *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions* – A. Bandivadekar, K. Bodek, L. Cheah, C. Evans, T. Groode, J. B. Heywood, E. Kasseris, M. Kromer, M. Weiss - Laboratory for Energy and the Environment Report No. LFEE 2008-05 RP - Massachusetts Institute of Technology – July 2008.

[70] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017* - Figure 45 p.60 – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[71] "How Much Are Electric Vehicles Driven?" – L. W. Davis – November 2018.

[72] *Essays on the Dynamics of Alternative Fuel Vehicle Adoption: Insights from the Market for Hybrid-Electric Vehicles in the United States* – D. R. Keith - Submitted to the Engineering Systems Division on August 7, 2012 in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy – September 2012.

[73] *A Dynamic Model of Vehicle Ownership, Type Choice, and Usage* – K. Gillingham, F. Iskhakov, A. Munk-Nielsen, J. Rust and B. Schjerning – 2 September 2015.

[74] *On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions* - I. B. Akerlind, P. Bastani, I. Berry, K. Bhatt, A. Chao, E. Chow, V. Karplus, D. Keith, M. Khusid, E. Nishimura, and S. Zoepf - Massachusetts Institute of Technology, Sloan Automotive Laboratory Engineering Systems Division 2015 - [J. B. Heywood and D. Mackenzie] - MIT Energy Initiative Report November 2015.

[75] *The Performance of Future ICE and Fuel Cell Powered Vehicles and Their Potential Fleet Impact* - Heywood et. al 2004.

[76] *Evaluat*ing the impact of advanced vehicles and fuel technologies in U.S. Light-Duty Vehicle Fleet - Equation 3.1 p.45 – A. Bandivadekar - Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy at the Massachusetts Institute of Technology – Department of Mechanical Engineering - 2008.

[77] "Factors Associated with Aggregate Scrappage Rate in the United States of America: 1962-1992" – S. Miaou – 1995.

[78] *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions – p.70* - A. Bandivadekar, K. Bodek, L. Cheah, C. Evans, T. Groode, J. B. Heywood, E. Kasseris, M. Kromer, M. Weiss - Laboratory for Energy and the Environment Report No. LFEE 2008-05 RP - Massachusetts Institute of Technology – July 2008.

[79] "Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries" - Adam Millard-Ball & Lee Schipper - Transport Reviews – 2010

[80] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017* - Figure 45 p.60 – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[81] *Spatiotemporal Lifecycle Assessment of the Light-Duty Vehicle Fleet of United States* – D. Wu - Submitted to the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy at the Massachusetts Institute of Technology – Department of Mechanical Engineering – 30 July 2018.

[82] *On the Road in 2035: Reducing Transportation's Petroleum Consumption and GHG Emissions* – Figure 27 *p.72* - A. Bandivadekar, K. Bodek, L. Cheah, C. Evans, T. Groode, J. B. Heywood, E. Kasseris, M. Kromer, M. Weiss - Laboratory for Energy and the Environment Report No. LFEE 2008-05 RP - Massachusetts Institute of Technology – July 2008.

[83] *On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions* – p.19 - I. B. Akerlind, P. Bastani, I. Berry, K. Bhatt, A. Chao, E. Chow, V. Karplus, D. Keith, M. Khusid, E. Nishimura, and S. Zoepf - Massachusetts Institute of Technology, Sloan Automotive Laboratory Engineering Systems Division 2015 - [J. B. Heywood and D. Mackenzie] - MIT Energy Initiative Report November 2015.

[84] *Energy datasheets: EU28 Data Sheet* - Energy Statistics Eu Comission, DG Energy, unit A4 - Other complementary sources: ECFIN/AMECO and EUROSTAT macro-economic data 1990-2017 (update May 2019) EUROSTAT CHP survey 2009-2016 (update March 2019).

[85] "Energy policies of IEA countries: Norway 2017 Review" – International Energy Agency IEA 2017.

[86] "Norway Statistics: Global energy data at your fingertips" - IEA Electricity Generation by fuel 1990 – 2016 - https://www.iea.org//statistics/?country=NORWAY&year=2016&category=Electricity&indicator=ElecGenByFuel&mode=chart&dataTable=ELECTRICITYANDHEAT

[87] "Energy facts Norway: Electricity Production" – Norwegian Ministry of Petroleum and Energy - 4 January 2019 - https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/

[88] *Documentation des facteurs d'émissions de la Base Carbone - Scope 2: émissions indirectes* – Agence de l'environement et de la maîtrise del'Énergie ADEME – 2014.

[89] "A Review of the Environmental Impacts of Biobased Materials" – M. Weiss, J. Haufe, M. Carus, M. Brandã˜o, S. Bringezu, B. Hermann, and M. K. Patel - RESEARCH AND ANALYSIS - Yale University 2012.

[90] "Life cycle assessment of solar PV based electricity generation systems: A review" - A.F. Sherwani, J.A. Usmani, Varun - Renewable and Sustainable Energy Reviews 14 540–544 2010 – 3 August 2009.

[91] "Life cycle assessment of ocean energy technologies" – A. Uihlein - LCA FOR ENERGY SYSTEMS AND FOOD PRODUCTS – 15 June 2015.

[92] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017 Table KF1: Progress in average fuel economy improvement in different regions and GFEI target for 2030 p.5* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[93] "World Population Prospects: Key Findings & Advanced Tables" – United Nations UN – Department of Economic and Social Affairs Population Division - 2017 Revision – Working Paper No. ESA/P/WP/248 – New York 2017.

[94] "Change in distance Travelled by Car" – Odysee-Mure – 2016 - https://www.odyssee-mure.eu/publications/efficiency-by-sector/transport/transport-eu.pdf

[95] World Nuclear Association – Information Library / country profiles - https://www.world-nuclear.org/information-library/country-profiles.aspx

[96] "Spain's booming hybrid electric vehicle market: A summary of supporting policy measures" – S. Wappelhorst – The International Council for Clean Transportation ICCT 2019 - 26 May 2019 - https://theicct.org/publications/spain-HEV-market-supporting-policy-measures

[97] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017- Table 2 p.5* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[98] "On the baseline to evolution of automobile fuel-economy in Europe" – T. Zachariadis – Energy Policy vol.34 1773-1785 – February 2006.

[99] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017 – Figure 15 p.30* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[100] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017 – Figure 18 p.33* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[101] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017 – Figure 12 p.28* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[102] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017 – Figure 16 p.31* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[103] *Fuel Economy in Major Car Markets Technology and Policy Drivers 2005-2017 – Figure 16 p.31* – International Energy Agency (IEA), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for all parts of the work except chapters 4 and Annex B, and International Energy Agency (IEA)/International Council on Clean Transportation (ICCT), 2019, (Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017). Licence: Creative Commons Attribution CC BY-NC-ND 3.0 IGO for chapters 4 and Annex B of the work – International Energy Agency IEA 2019.

[104] *On the Road toward 2050: Potential for Substantial Reductions in Light-Duty Vehicle Energy Use and Greenhouse Gas Emissions* – p.28 - I. B. Akerlind, P. Bastani, I. Berry, K. Bhatt, A. Chao, E. Chow, V. Karplus, D. Keith, M. Khusid, E. Nishimura, and S. Zoepf - Massachusetts Institute of Technology, Sloan Automotive Laboratory Engineering Systems Division 2015 - [J. B. Heywood and D. Mackenzie] - MIT Energy Initiative Report November 2015.

Appendix A: New LDV registrations profiles used for major European countries in Fleet Model calculations

Table A - 1: Sales profile from 1980 to 2017, used as new registrations input for Fleet Model in total French LDV GHG emissions calculations

		Sources:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline	CAR sales	ACEA, SDES	1691837	1613956	1842046	1812784	1505968	1483952	1593617	1710026	1680976	1582851	1530099	1237501	1270348	926809	1020370	1017327	1276867	979037	1137837
	SUV sales		5090	6156	8513	9842	9395	10461	12528	14834	15951	16311	17018	13764	14129	11257	13440	15493	19444	17946	24407
	OLT sales		136704	134714	132351	129613	126502	123016	119157	114923	109925	106956	99979	87518	81826	61384	49457	37841	29916	24863	22919
Diesel	CAR sales	ACEA, European Market Stadistics Report 2018-2019	184290	436488	206751	198542	246012	266618	316363	362676	511366	671894	753631	771429	812189	773758	926901	884219	823243	703158	764901
	SUV sales		555	1665	955	1078	1535	1879	2487	3146	4853	6924	8382	8580	9034	9398	12208	13465	12537	12889	16408
	OLT sales		164658	175982	187679	199751	212196	225016	238209	251777	264775	284344	294721	256282	238674	192516	236943	274959	301484	286757	323068
HEV	CAR sales	SDES, European Market Stadistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	SDES, Eurostat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEV	CAR sales	SDES, European Market Stadistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		Sources:	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	CAR sales	ACEA, SDES	1166141	1050191	946433	754604	621853	584424	596012	529689	493399	436197	645912	621365	557493	445990	500648	556284	690698	817415	932301
	SUV sales		34828	38090	40463	35640	33418	34670	40074	36642	38282	21177	25026	27173	34388	34706	34690	39182	51629	67276	73838
	OLT sales		22453	21933	25399	18528	15991	14900	10846	11820	9378	8566	7452	4154	4267	7625	7300	7407	11332	6535	10936
Diesel	CAR sales	ACEA, European Market Stadistics Report 2018-2019	919978	1009007	1215855	1293724	1284784	1315451	1338825	1335413	1415847	1511098	1561094	1526522	1503350	1E+06	1121871	1071222	1020820	970540	924871
	SUV sales		27476	36596	51981	61103	69046	78035	90017	92378	109850	73360	60485	66759	92733	99966	77735	75451	76304	79878	73245
	OLT sales		351854	391992	407458	385493	364853	392615	408122	427372	451135	450371	365138	411294	422384	373613	357691	362954	366409	396290	419918
HEV	CAR sales	SDES, European Market Stadistics Report 2018-2019	0	0	0	0	30	632	2675	5998	6644	8055	9501	9258	12843	25818	42914	38537	51089	47004	68672
	SUV sales		0	0	0	0	2	37	180	415	515	391	368	405	792	2009	2973	2714	3819	3869	5438
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	409	437
PHEV	CAR sales	SDES, Eurostat	0	0	0	0	0	0	0	0	0	0	0	0	0	0	788	1800	5200	6864	6884
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	55	127	389	565	545
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2656	3062
BEV	CAR sales	SDES, European Market Stadistics Report 2018-2019	0	0	0	0	107	434	6	13	6	4	12	179	2477	5252	8212	9872	16068	20103	23082
	SUV sales		0	0	0	0	6	26	0	1	0	0	0	8	153	409	569	695	1201	1655	1828
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2656	3062
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	10	9	48
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A - 2: Sales profile from 1980 to 2017, used as new registrations input for Fleet Model in total German LDV GHG emissions calculation

		Sources:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline	CAR sales	ACEA, KBA, European Market Stadistics Report 2018-2019	2372086	2675662	2623478	2571900	2520924	2200735	2296895	2390388	2481230	2569434	2655017	3568916	3240848	3E+06	2596198	2734346	2879744	2909403	2967629
	SUV sales		26604	35742	40689	45447	50016	48460	55604	63123	70998	79219	87769	99034	107136	98202	80295	99173	92128	93077	110825
	OLT sales		79655	74244	69017	63975	59118	54446	51904	49139	46373	43608	41511	47683	53813	57104	47572	39444	33103	31471	28859
Diesel	CAR sales	ACEA, KBA, European Market Stadistics Report 2018-2019	27192	54605	77426	99741	121554	127264	155306	185461	217715	252053	288461	477474	562964	449565	516749	463719	508190	509402	633862
	SUV sales		305	729	1201	1762	2412	2802	3760	4897	6230	7771	9536	13250	18610	16789	15982	16819	16258	16297	23671
	OLT sales		87715	88319	88739	88974	89024	88889	92019	94784	97550	100315	104766	119632	134540	152287	182857	212023	226723	236714	247685
HEV	CAR sales	Vehicle Market Statistics Report 2001-2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	Vehicle Market Statistics Report 2001-2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEV	CAR sales	Vehicle Market Statistics Report 2001-2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		Sources:	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	CAR sales	ACEA, KBA, European Market Stadistics Report 2018-2019	2820667	2236970	2068124	1894913	1806569	1685541	1768103	1752547	1466282	1534828	2426334	1500180	1451838	1E+06	1289850	1307041	1355517	1437938	1606150
	SUV sales		129822	117735	120367	126112	137860	140614	153748	174599	172022	185638	205550	183524	213496	236576	231201	245633	278618	319989	396154
	OLT sales		28021	26875	26794	21932	19567	16996	13566	13807	12540	12234	10384	6268	6421	6433	6383	6794	6873	8264	10129
Diesel	CAR sales	ACEA, KBA, European Market Stadistics Report 2018-2019	814213	972456	1089800	1155004	1200870	1326723	1282562	1394910	1345689	1216223	1076466	1087685	1302044	1E+06	1187737	1220660	1268634	1256021	1066981
	SUV sales		37474	51182	63427	76869	91639	110680	111527	138969	157874	147103	91194	133061	191468	222607	212896	229399	260743	279504	263167
	OLT sales		256882	266388	249146	236685	221727	206975	193081	193406	195239	196111	162684	150443	154114	154400	153204	163055	173625	196269	157000
HEV	CAR sales	Vehicle Market Statistics Report 2001-2017	0	0	0	0	0	3015	3054	6308	5635	5513	7020	10394	11067	18337	20029	17894	15957	27415	44308
	SUV sales		0	0	0	0	0	252	266	628	661	667	595	1271	1627	3241	3590	3363	3280	6101	10928
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	181	207	169
PHEV	CAR sales	Vehicle Market Statistics Report 2001-2017	0	0	0	0	0	0	0	0	0	0	0	0	232	1047	1404	3705	9217	10947	23362
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	34	185	252	696	1894	2436	5762
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	930	760
BEV	CAR sales	Vehicle Market Statistics Report 2001-2017	0	0	0	0	0	0	0	0	0	61	15	128	1594	2171	4633	7053	10035	9196	19603
	SUV sales		0	0	0	0	0	0	0	0	0	7	1	16	234	384	831	1325	2062	2047	4835
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	930	760
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	3	86	13	11
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A - 3: Sales profile from 1980 to 2017, used as new registrations input for Fleet Model in total Dutch LDV GHG emissions calculation

		Sources:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline	CAR sales	ACEA	462859	461650	460405	459125	457808	456455	455065	453640	452178	450680	444706	435025	432727	346702	379632	382592	396576	392141	425829
	SUV sales		2482	2553	2624	2694	2764	2832	2901	2968	3035	3101	3135	1747	2175	2092	2292	3086	3198	4361	6924
	OLT sales		34229	32809	31378	29934	28478	27011	25531	24040	22537	21021	19494	19668	19801	18776	13226	9052	6570	5731	5439
Diesel	CAR sales	ACEA	17119	20743	24402	28096	31826	35591	39392	43227	47098	51005	54403	53767	56783	42851	51768	61766	71637	80888	108461
	SUV sales		92	115	139	165	192	221	251	283	316	351	383	216	285	259	312	498	578	900	1764
	OLT sales		42167	43882	45609	47347	49098	50860	52635	54421	56219	58029	59852	59973	60135	61454	67300	71768	74546	75679	90471
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, OFV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, OFV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, OFV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		Sources:	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	CAR sales	ACEA	460738	451580	395316	386725	363057	347043	319597	329804	335601	343507	280677	358988	372037	322843	248159	237962	244238	261175	300663
	SUV sales		11330	11579	13068	13819	15403	16734	18243	20009	23331	19034	12397	11141	10717	11467	18679	14732	16913	15184	14690
	OLT sales		4971	4144	4090	2899	2464	2302	1040	1085	838	732	513	992	1760	1684	1507	2061	1721	1822	2413
Diesel	CAR sales	ACEA	136073	131104	117435	106358	105888	113527	117797	123289	133768	118797	74489	93468	152791	136892	96218	98909	121439	68497	69255
	SUV sales		3346	3362	3882	3800	4493	5474	6724	7480	9299	6582	3290	2901	4401	4862	7242	6123	8409	3982	3384
	OLT sales		93680	91502	79263	77356	74012	83824	64188	62828	79992	83922	50762	48615	56907	54464	48715	49462	55655	67959	70191
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, OFV	0	0	513	0	0	923	2640	3194	3309	11368	15573	15445	14588	21837	22088	13504	13855	10483	16600
	SUV sales		0	0	17	0	0	45	151	194	230	630	688	479	420	776	1663	836	959	609	811
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, OFV	0	0	0	0	0	0	0	0	0	0	29	109	670	2858	16307	11314	36947	17713	1581
	SUV sales		0	0	0	0	0	0	0	0	0	0	1	3	19	102	1227	700	2558	1030	77
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	233	93
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, OFV	0	0	0	0	0	0	0	0	0	0	8	32	195	830	4734	3285	3359	3615	7114
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	1	6	29	356	203	233	210	348
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	419
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	14	14	15
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A - 4: Sales profile from 1980 to 2017, used as new registrations input for Fleet Model in total Norwegian LDV GHG emissions calculation

		Sources:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline	CAR sales	ACEA	42305	43893	45481	46725	48061	50072	52711	54724	56647	58441	59930	50375	52264	50755	75356	83456	111587	112628	100716
	SUV sales		32	66	68	35	36	38	79	41	85	176	362	406	688	1248	1459	1616	4408	7189	9356
	OLT sales		4189	4363	4536	4710	4884	5057	5231	5405	5578	5752	5926	6128	6321	6162	4581	3359	2628	2407	1989
Diesel	CAR sales	ACEA	494	778	1094	1791	2360	2255	1481	1414	1353	1373	1600	3444	6328	8608	8095	5327	8658	7445	7233
	SUV sales		0	1	2	1	2	2	2	1	2	4	10	28	83	212	157	103	342	475	672
	OLT sales		11950	12445	12941	13436	13931	14427	14922	15417	15913	16408	16903	17370	17846	18674	20924	22815	24215	25105	24871
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		Sources:	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	CAR sales	ACEA	84792	78776	70934	63153	57282	66103	51985	39429	23611	20484	17171	19471	18784	26357	33371	29845	29143	28233	24617
	SUV sales		8182	9836	8803	10068	11732	17045	14070	14956	6621	6529	5952	6490	5684	10255	15997	14324	15591	16420	15977
	OLT sales		1713	1701	2013	1184	1216	1389	1193	1494	1303	938	663	623	733	750	617	1185	1329	1368	681
Diesel	CAR sales	ACEA	7574	7791	10834	13368	17353	25835	33907	38567	75071	60738	53286	71785	80357	63735	50488	47423	40062	30120	22222
	SUV sales		731	973	1345	2131	3554	6662	9177	14629	21051	19360	18470	23928	24315	24798	24198	22760	21420	17502	14391
	OLT sales		23526	26225	28221	20810	23096	29725	33854	41117	44306	33932	22841	28417	34780	31098	30237	28428	31906	34562	34413
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	605	1148	2220	2474	2711	4264	5523	5910	6438	6723	6971	11049	12229
	SUV sales		0	0	0	0	0	0	164	435	622	789	940	1421	1671	2299	3086	3227	3727	6421	7919
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, EAFO	0	0	0	0	0	0	0	0	0	0	0	0	1	245	219	1169	5204	13494	18970
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	95	105	561	2782	7841	12285
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019, EAFO	0	0	0	0	0	0	0	0	0	184	108	296	1543	3076	5573	12277	16790	14863	18199
	SUV sales		0	0	0	0	0	0	0	0	0	59	37	99	467	1197	2671	5892	8977	8637	11786
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	681
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	17	23	55
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A - 5: Sales profile from 1980 to 2017, used as new registrations input for Fleet Model in total Spanish LDV GHG emissions calculation

		Sources:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline	CAR sales	ACEA, DGT	540132	460291	471197	447277	398271	449356	592705	809286	941273	1011982	867671	798197	843933	607537	693545	584778	598431	622366	660147
	SUV sales		541	922	944	448	399	450	1188	810	1886	4064	6997	1600	845	608	694	1172	599	1247	2651
	OLT sales		42669	35628	38546	41133	36107	42889	49569	60261	66359	68910	61656	57090	58624	39140	30338	22591	19310	20711	20048
Diesel	CAR sales	ACEA, DGT	33443	44414	63464	102609	123436	125121	94968	118050	125809	132794	131287	114035	163513	167149	244487	283978	368964	466642	617691
	SUV sales		33	89	127	103	124	125	190	118	252	533	1059	229	164	167	245	569	369	935	2481
	OLT sales		49839	45072	52852	61191	58355	75432	95059	126318	152483	174180	172133	158375	162018	115964	134336	146956	168223	202880	232853
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		Sources:	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	CAR sales	ACEA, DGT	732836	679921	715457	601498	588351	573713	536305	510899	441387	340255	270735	269916	221212	197251	216424	267259	349090	446297	545224
	SUV sales		2943	2046	3523	1689	4625	4627	4871	6153	51232	31730	23287	22676	17910	17082	14158	17635	26809	40172	50264
	OLT sales		21823	19024	19331	15120	15959	16253	14650	15271	12786	6687	4407	3741	3337	2733	2340	2339	4118	3934	5643
Diesel	CAR sales	ACEA, DGT	763685	782837	776048	802984	892534	1066854	1123650	1128325	1019576	740812	619053	646043	525776	447135	469714	555242	646674	648370	621301
	SUV sales		3067	2356	3821	2255	7016	8604	10205	13589	118344	69084	53246	54275	42569	38723	30727	36637	49662	58361	57277
	OLT sales		276704	268334	249858	240394	272329	308761	356421	361872	362895	199955	126451	135137	124301	91375	89382	116597	148932	156509	170491
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	1662	1641	2928	3253	4471	6458	9077	9156	9754	11690	18290	30470	55293
	SUV sales		0	0	0	0	0	0	15	20	340	303	385	543	735	793	638	771	1405	2743	5097
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1016	1129	3230
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	102	298
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	403	443
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	92	378	458	836	835	1016	2257	3686
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	8	31	40	55	55	78	203	340
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	403	443
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A - 6: Sales profile from 1980 to 2017, used as new registrations input for Fleet Model in total British LDV GHG emissions calculation

		Sources:	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Gasoline	CAR sales	ACEA, DFT	2055805	2396908	2733958	2616368	2369934	2226791	2180466	2092257	2145485	1947277	1837114	1414541	1348385	1E+06	1434914	1482544	1593329	1742925	1808373
	SUV sales		3432	6569	10428	12796	14146	15698	22470	28417	36216	39335	43248	39253	46015	54740	61346	69858	71591	78313	95177
	OLT sales		95872	107348	117328	107329	92679	82765	76931	69806	67399	57311	50364	40126	40281	42470	32026	22234	16739	15445	13013
Diesel	CAR sales	ACEA, DFT	37683	55423	76443	85933	89524	95202	104180	110583	124389	122973	125615	134792	192626	325061	397671	375281	345027	334459	326660
	SUV sales		63	152	292	420	534	671	1074	1502	2100	2484	2957	3740	6574	12840	17002	17683	15503	15028	17193
	OLT sales		118106	143576	170542	169765	159784	155844	158599	158027	168131	158207	154630	122356	122331	139002	162967	176273	189940	203950	216440
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

		Sources:	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Gasoline	CAR sales	ACEA, DFT	1793944	1803452	1889966	1827579	1731620	1583260	1400227	1315722	1299356	1094152	1061808	981950	846256	881517	981413	1045310	1123630	1124923	1136746
	SUV sales		100401	104963	131388	133343	142834	147079	136795	122383	123816	94110	86713	89931	89040	98055	122415	138910	162118	190921	219447
	OLT sales		11304	10070	12204	9377	9537	8632	5063	5475	3453	2484	1853	0	0	0	0	0	0	0	0
Diesel	CAR sales	ACEA, DFT	287197	296026	408983	561725	650906	763442	817910	821012	880138	855064	769659	857857	888059	934692	1002762	1094723	1113362	1098862	894766
	SUV sales		16073	17229	28432	40984	53690	70921	79906	76367	83869	73546	62855	78566	93438	103970	125077	145475	160633	186493	172723
	OLT sales		213001	222353	236482	250197	286516	314269	312456	316863	329555	284674	183464	221880	259532	238767	270238	320909	371123	373764	359416
HEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	2349	4445	8581	15364	13741	12911	20465	21077	22079	26177	32789	39125	43740	57498
	SUV sales		0	0	0	0	0	218	434	798	1464	1182	1054	1874	2218	2456	3265	4357	5645	7423	11099
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PHEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1611	6558	16110	25323	29814
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	201	871	2324	4298	5755
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	562	1085
BEV	CAR sales	European Vehicle Market Statistics Report 2018-2019	0	0	0	0	0	0	0	0	0	0	0	186	1054	1656	1611	6558	9206	9208	10648
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	17	111	184	201	871	1328	1563	2055
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	562	1085
FCEV	CAR sales	EAFO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	11	22	32	67
	SUV sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	OLT sales		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix B: In-use stock Fleet Model calibration with median life-time variations

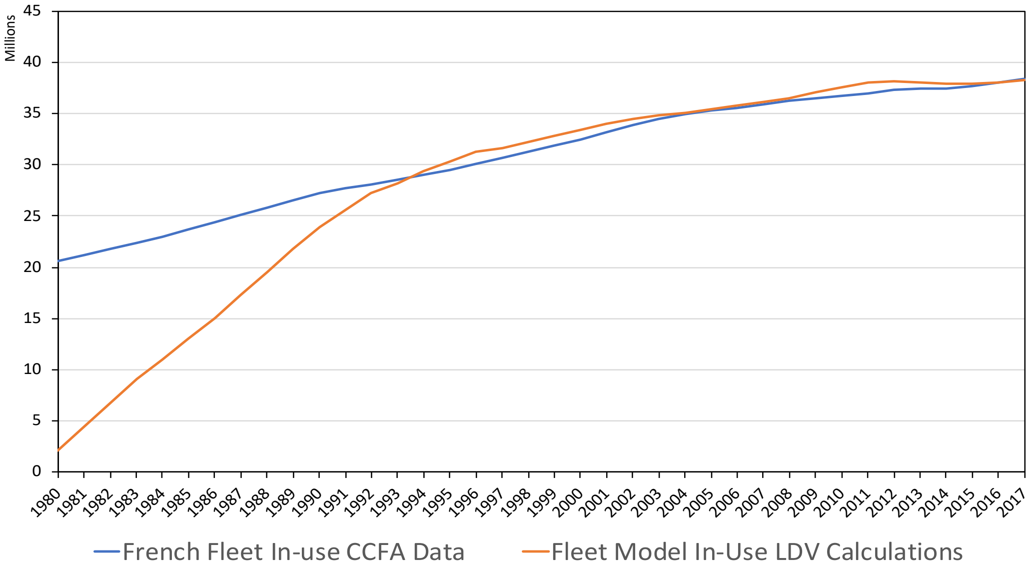

Figure B - 1: In-use vehicle stock Fleet Model calibration. Case applied to French LDV fleet.

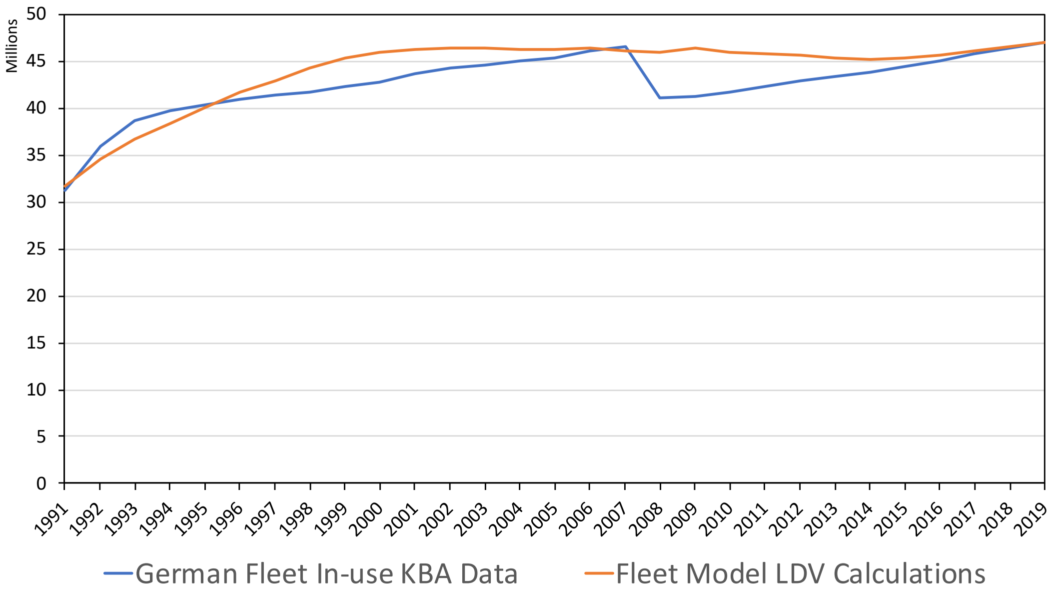

Figure B - 2: In-use vehicle stock Fleet Model calibration. Case applied to German LDV fleet.

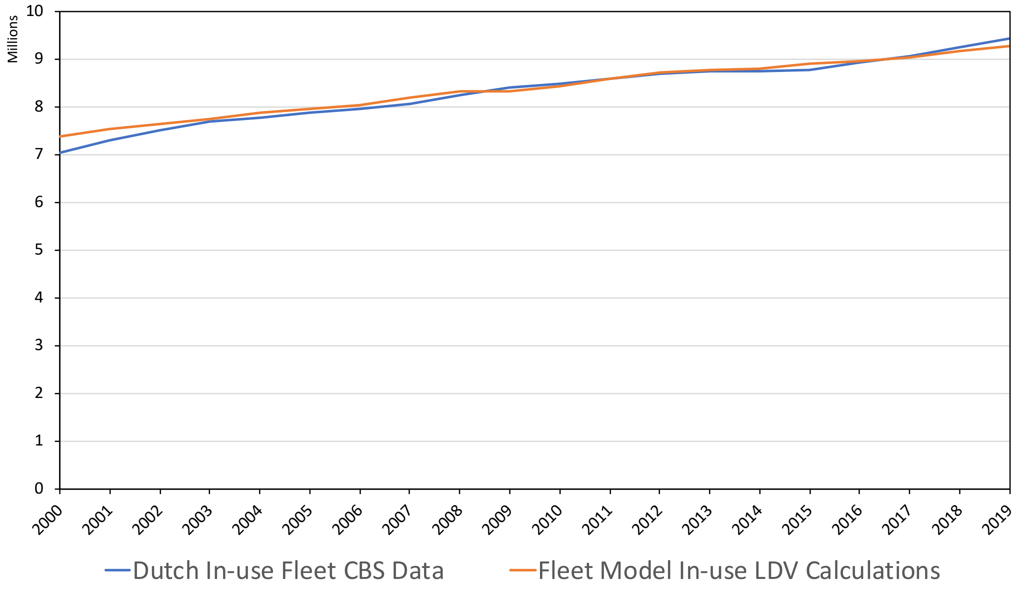

Figure B - 3: In-use vehicle stock Fleet Model calibration. Case applied to Dutch LDV fleet.

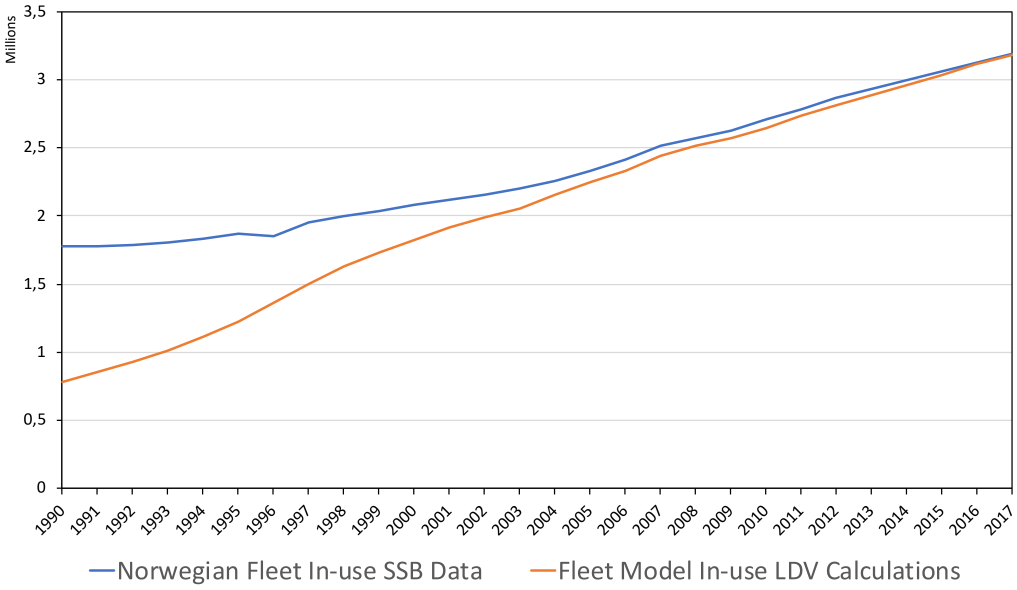

Figure B - 4: In-use vehicle stock Fleet Model calibration. Case applied to Norwegian LDV fleet.

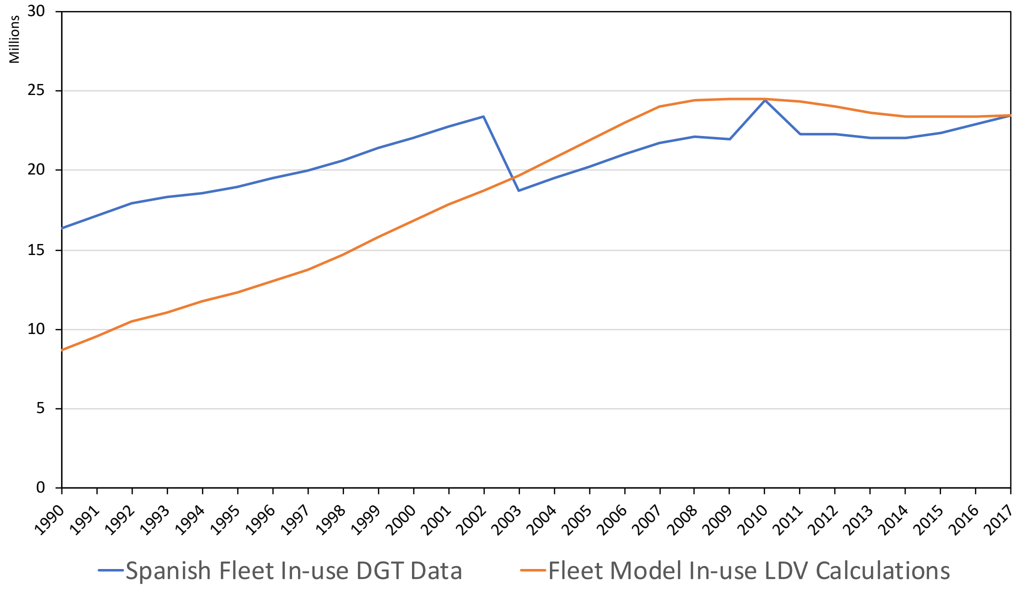

Figure B - 5: In-use vehicle stock Fleet Model calibration. Case applied to Spanish LDV fleet.

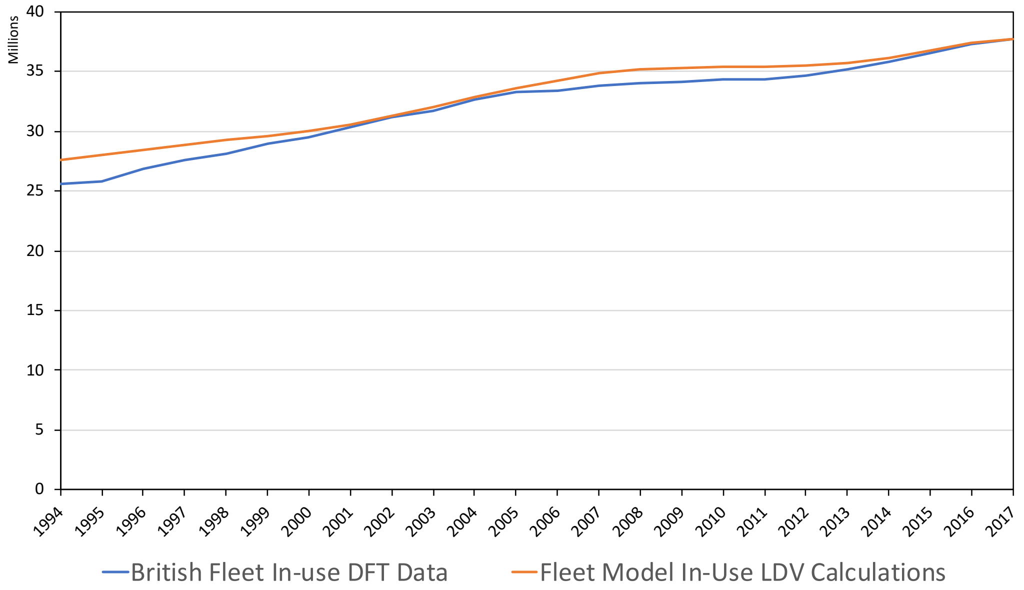

Figure B - 6: In-use vehicle stock Fleet Model calibration. Case applied to British LDV fleet.

Appendix C: Fuel consumption profiles development

The fuel consumption profiles represent the evolution each vehicle segment and powertrain has experienced in the previous years. It represents a very important input since it is directly linked to the total LDV fleet GHG emissions in each of the analyzed European countries. Differences between European countries are found, however the overall tendency in having more fuel-efficient vehicles is encountered.

Table C - 1: Fuel consumption recent evolution trends in global regions [98].

<table>
<tr><td colspan="3"></td><td>2005</td><td>2010</td><td>2015</td><td>2017</td><td>2030</td></tr>
<tr><td rowspan="3">Advanced (Gasoline price ≥ USD 1/L)</td><td colspan="2">average fuel economy (Lge/100km)</td><td>7.4</td><td>6.5</td><td>5.8</td><td>5.8</td><td rowspan="12">4.4</td></tr>
<tr><td colspan="2" rowspan="2">annual improvement rate (% per year)</td><td colspan="2">-2.4%</td><td>-2.5%</td><td>-0.1%</td></tr>
<tr><td colspan="4">-2.0%</td></tr>
<tr><td rowspan="3">Advanced (Gasoline price < USD 1/L)</td><td colspan="2">average fuel economy (Lge/100km)</td><td>11.0</td><td>9.5</td><td>8.6</td><td>8.6</td></tr>
<tr><td colspan="2" rowspan="2">annual improvement rate (% per year)</td><td colspan="2">-2.9%</td><td>-1.9%</td><td>-0.4%</td></tr>
<tr><td colspan="4">-2.0%</td></tr>
<tr><td rowspan="3">Emerging</td><td colspan="2">average fuel economy (Lge/100km)</td><td>8.6</td><td>8.5</td><td>7.8</td><td>7.5</td></tr>
<tr><td colspan="2" rowspan="2">annual improvement rate (% per year)</td><td colspan="2">-0.2%</td><td>-1.6%</td><td>-2.3%</td></tr>
<tr><td colspan="4">-1.2%</td></tr>
<tr><td rowspan="3">Global average</td><td colspan="2">average fuel economy (Lge/100km)</td><td>8.8</td><td>8.0</td><td>7.4</td><td>7.2</td></tr>
<tr><td colspan="2" rowspan="2">annual improvement rate (% per year)</td><td colspan="2">-2.0%</td><td>-1.5%</td><td>-1.4%</td></tr>
<tr><td colspan="4">-1.7%</td></tr>
<tr><td rowspan="2">GFEI target</td><td rowspan="2">Required annual improvement rate (% per year)</td><td>2005 base year</td><td colspan="5">-2.8%</td></tr>
<tr><td>2017 base year</td><td colspan="3"></td><td colspan="2">-3.7%</td></tr>
</table>

Replicating the tendency shown in Table C-1, it is possible to extrapolate from current date the evolution curve of fuel consumption for the past years. Before 2005, the trend is extrapolated from other relevant reports [99].

Also, differences between segments and powertrain technology are considered. By assuming average differences at current date (2017) to be kept over previous trends, it is possible to extrapolate as well the evolution applied to each segment and powertrain technology.

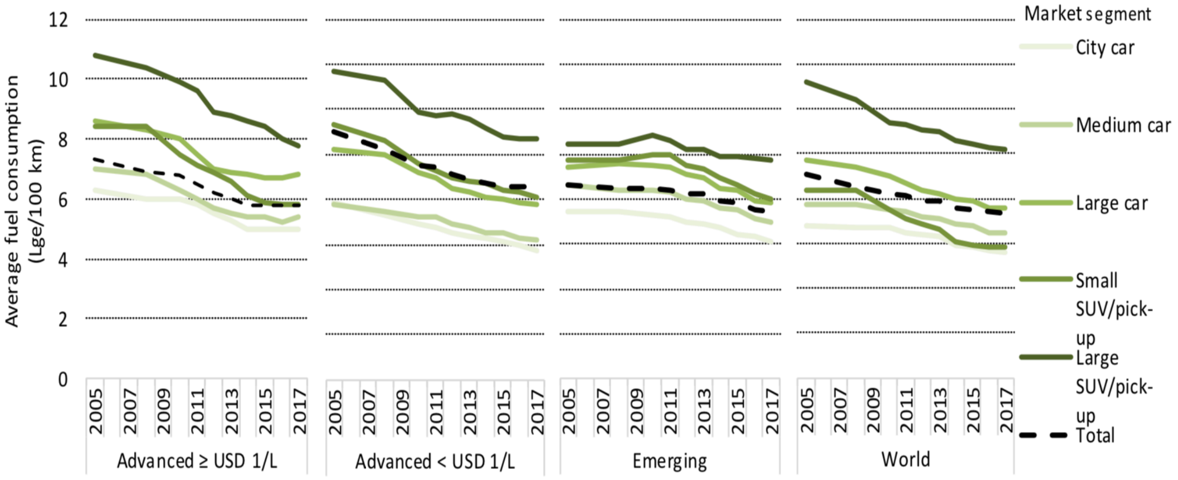

Figure C - 1: Average fuel consumption evolution by world region for each vehicle segment [101].

In Figure C-1 it can be appreciated the gap between different vehicle segments for advanced countries with fuel prices higher than 1$ dollar per liter.

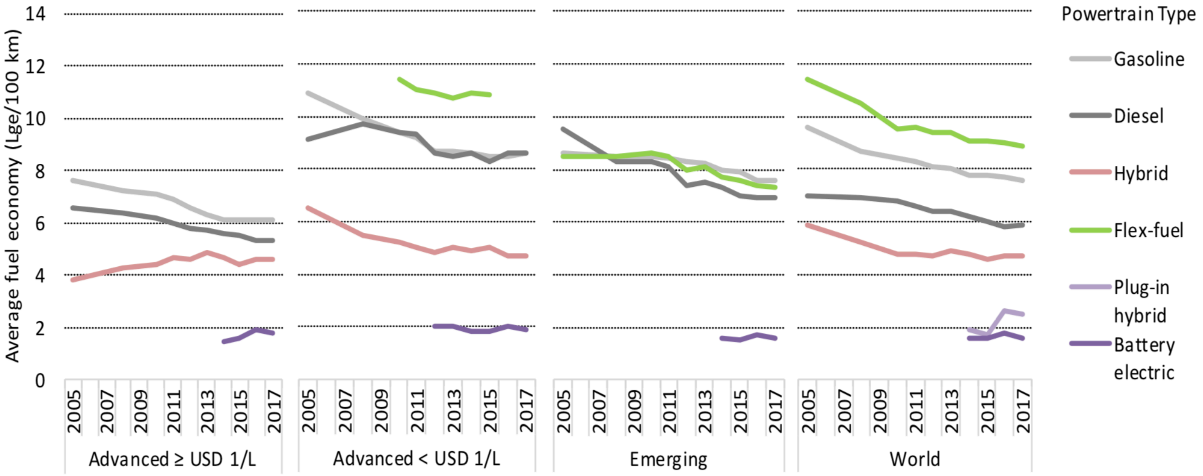

Figure C - 2: Average fuel consumption evolution by world region for each powertrain technology [102].

Following the same logic, fuel consumption evolutions of different powertrain technologies are extrapolated by identifying the existing gap between them in 2017. Comparing the actual average fuel consumption of the total LDV in a specific country with the value obtained while multiplying the current fleet composition by the overall current average of each vehicles segment and powertrain technology fuel consumption's, allows to identify the deviations with respect overall averages for particular country studied.

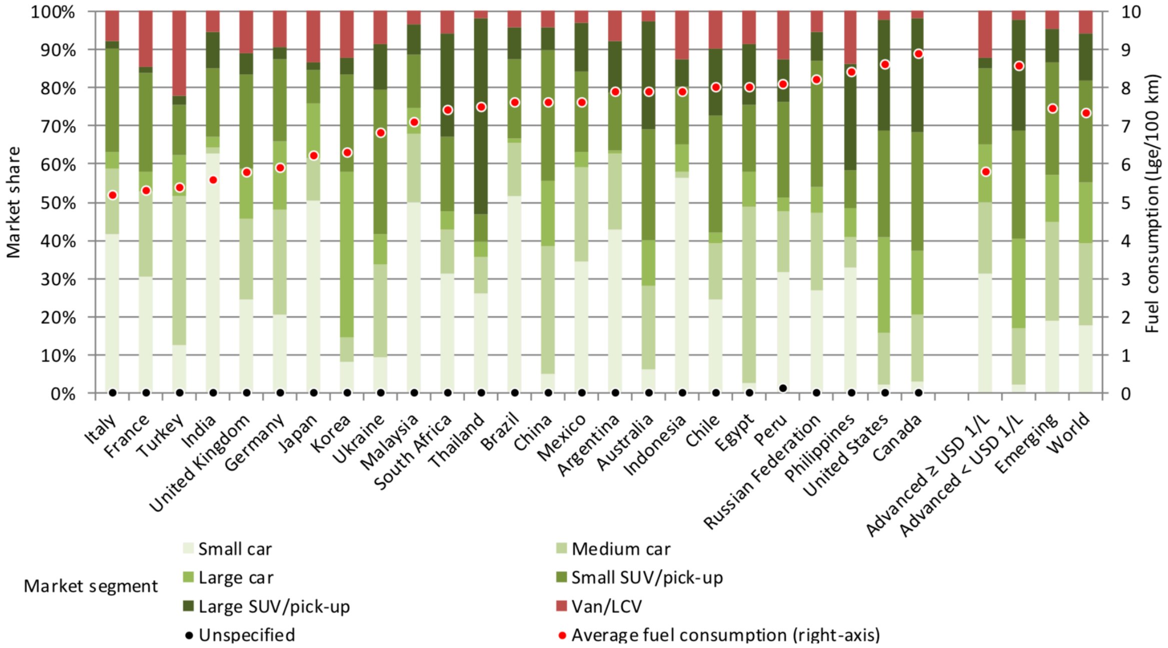

Figure C - 3: Vehicle segment fleet LDV penetration and average fuel consumption in several countries [103].

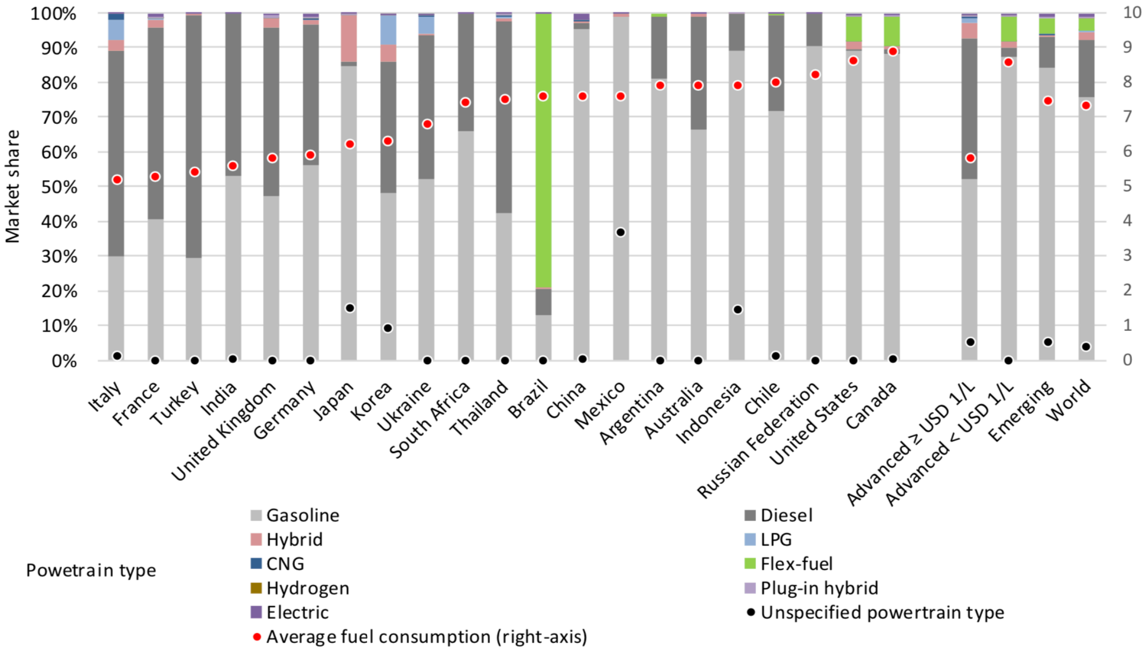

Figure C - 4: Vehicle powertrain technology LDV fleet penetration and average fuel consumption in several countries [104].

Knowing the countries fleet penetrations, shown in Figure C-3 and C-4 for major countries, it is possible to correct from overall average fuel consumptions and obtain specificity at each studied country.

Another important aspect to consider is the potential for HEV to reduce fuel consumption with respect ICEVs. It is assumed that for all the evolution curves, hybrid powertrain technologies obtain a 30% benefit with respect their homologous size gasoline combustion engine vehicles [7].

Also, it is important to include the utility factor for PHEV, as it represents the percentage of kilometers driven using the electric motor. For all the cases studied in the Fleet Model, it is assumed to be as presented in Table 2-C and depends on the vehicle segment size.

Table C - 2: Utility factors assumed in Fleet Model for percentage of kilometers in PHEV using electricity [105].

Vehicle Segment	PHEV Utility factor
Car	60%
SUV	50%
OLT	40%

Last but not least, as the values presented are obtained from test cycle data, mostly WLTP cycles, the real on road fuel consumption is likely be higher. Therefore, a 20% increase with respect the input data is applied to consider these well-grounded discrepancies.

Following tables present the fuel consumption evolutions for the six countries studied. From 1980 to 2017 they represent input data, while from 2018 to 2050 they constitute estimated fuel consumptions for Reference Scenarios.

Table C - 3: France fuel consumption evolution in L / 100 km per vehicles segment and powertrain technology. Profiles used for Fleet Model calculations.

		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Car FC	Gasoline	12,10	11,97	11,84	11,71	11,58	11,46	11,33	11,21	11,09	10,97	10,85	10,72	10,58	10,43	10,27	10,10	9,92	9,73	9,54
	Diesel	10,10	9,99	9,88	9,77	9,66	9,56	9,45	9,35	9,25	9,15	9,05	8,94	8,83	8,72	8,60	8,48	8,35	8,22	8,08
	HEV																			
	PHEV																			
SUV FC	Gasoline	13,54	13,39	13,24	13,10	12,96	12,82	12,68	12,54	12,40	12,27	12,13	11,99	11,83	11,66	11,48	11,29	11,09	10,88	10,67
	Diesel	11,29	11,17	11,05	10,93	10,81	10,69	10,57	10,46	10,35	10,23	10,12	10,00	9,88	9,75	9,62	9,48	9,34	9,19	9,04
	HEV																			
	PHEV																			
OLT FC	Gasoline	17,13	16,94	16,76	16,57	16,39	16,21	16,04	15,86	15,69	15,52	15,35	15,17	14,97	14,75	14,53	14,29	14,03	13,77	13,50
	Diesel	14,29	14,13	13,98	13,83	13,67	13,53	13,38	13,23	13,09	12,95	12,81	12,66	12,50	12,34	12,17	11,99	11,81	11,63	11,43
	HEV																			
	PHEV																			

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Car FC	Gasoline	9,34	9,13	8,93	8,73	8,54	8,35	8,15	7,96	7,78	7,59	7,42	7,24	7,06	6,89	6,72	6,56	6,40	6,39	6,39
	Diesel	7,94	7,80	7,66	7,52	7,39	7,25	7,08	6,92	6,76	6,60	6,44	6,29	6,14	5,99	5,84	5,70	5,56	5,56	5,55
	HEV					5,98	5,84	5,71	5,57	5,44	5,32	5,19	5,07	4,95	4,82	4,71	4,59	4,48	4,48	4,47
	PHEV					5,98	5,84	5,71	5,57	5,44	5,32	5,19	5,07	4,95	4,82	4,71	4,59	4,48	4,48	4,47
SUV FC	Gasoline	10,44	10,21	9,99	9,76	9,55	9,34	9,12	8,90	8,70	8,49	8,29	8,10	7,90	7,71	7,52	7,34	7,16	7,15	7,14
	Diesel	8,88	8,72	8,57	8,41	8,26	8,11	7,92	7,74	7,56	7,38	7,21	7,04	6,87	6,70	6,53	6,37	6,22	6,21	6,21
	HEV					6,68	6,54	6,38	6,23	6,09	5,94	5,81	5,67	5,53	5,40	5,26	5,14	5,01	5,01	5,00
	PHEV					6,68	6,54	6,38	6,23	6,09	5,94	5,81	5,67	5,53	5,40	5,26	5,14	5,01	5,01	5,00
OLT FC	Gasoline	13,21	12,92	12,63	12,36	12,08	11,81	11,54	11,27	11,00	10,75	10,49	10,25	10,00	9,75	9,52	9,28	9,06	9,05	9,04
	Diesel	11,24	11,04	10,84	10,64	10,45	10,26	10,02	9,79	9,56	9,34	9,12	8,90	8,69	8,47	8,27	8,07	7,87	7,86	7,85
	HEV					8,46	8,27	8,08	7,89	7,70	7,52	7,35	7,17	7,00	6,83	6,66	6,50	6,34	6,33	6,33
	PHEV					8,46	8,27	8,08	7,89	7,70	7,52	7,35	7,17	7,00	6,83	6,66	6,50	6,34	6,33	6,33

		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Car FC	Gasoline	6,32	6,26	6,20	6,14	6,07	6,01	5,95	5,89	5,84	5,78	5,72	5,66	5,61	5,55	5,49	5,44	5,38	5,33	5,28
	Diesel	5,49	5,44	5,39	5,33	5,28	5,23	5,17	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,77	4,73	4,68	4,63	4,59
	HEV	4,43	4,38	4,34	4,30	4,25	4,21	4,17	4,13	4,08	4,04	4,00	3,96	3,92	3,88	3,85	3,81	3,77	3,73	3,69
	PHEV	4,43	4,38	4,34	4,30	4,25	4,21	4,17	4,13	4,08	4,04	4,00	3,96	3,92	3,88	3,85	3,81	3,77	3,73	3,69
SUV FC	Gasoline	7,07	7,00	6,93	6,86	6,79	6,73	6,66	6,59	6,53	6,46	6,40	6,33	6,27	6,21	6,14	6,08	6,02	5,96	5,90
	Diesel	6,14	6,08	6,02	5,96	5,90	5,84	5,79	5,73	5,67	5,61	5,56	5,50	5,45	5,39	5,34	5,29	5,23	5,18	5,13
	HEV	4,95	4,90	4,85	4,80	4,76	4,71	4,66	4,61	4,57	4,52	4,48	4,43	4,39	4,34	4,30	4,26	4,22	4,17	4,13
	PHEV	4,95	4,90	4,85	4,80	4,76	4,71	4,66	4,61	4,57	4,52	4,48	4,43	4,39	4,34	4,30	4,26	4,22	4,17	4,13
OLT FC	Gasoline	8,95	8,86	8,77	8,68	8,60	8,51	8,42	8,34	8,26	8,17	8,09	8,01	7,93	7,85	7,77	7,70	7,62	7,54	7,47
	Diesel	7,78	7,70	7,62	7,54	7,47	7,39	7,32	7,25	7,17	7,10	7,03	6,96	6,89	6,82	6,75	6,69	6,62	6,55	6,49
	HEV	6,26	6,20	6,14	6,08	6,02	5,96	5,90	5,84	5,78	5,72	5,67	5,61	5,55	5,50	5,44	5,39	5,33	5,28	5,23
	PHEV	6,26	6,20	6,14	6,08	6,02	5,96	5,90	5,84	5,78	5,72	5,67	5,61	5,55	5,50	5,44	5,39	5,33	5,28	5,23

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	Gasoline	5,22	5,17	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,77	4,72	4,68	4,63	4,58
	Diesel	4,54	4,49	4,45	4,40	4,36	4,32	4,27	4,23	4,19	4,15	4,11	4,06	4,02	3,98
	HEV	3,66	3,62	3,58	3,55	3,51	3,48	3,44	3,41	3,37	3,34	3,31	3,27	3,24	3,21
	PHEV	3,66	3,62	3,58	3,55	3,51	3,48	3,44	3,41	3,37	3,34	3,31	3,27	3,24	3,21
SUV FC	Gasoline	5,84	5,78	5,73	5,67	5,61	5,56	5,50	5,45	5,39	5,34	5,28	5,23	5,18	5,13
	Diesel	5,08	5,03	4,98	4,93	4,88	4,83	4,78	4,73	4,68	4,64	4,59	4,55	4,50	4,45
	HEV	4,09	4,05	4,01	3,97	3,93	3,89	3,85	3,81	3,77	3,74	3,70	3,66	3,63	3,59
	PHEV	4,09	4,05	4,01	3,97	3,93	3,89	3,85	3,81	3,77	3,74	3,70	3,66	3,63	3,59
OLT FC	Gasoline	7,39	7,32	7,25	7,17	7,10	7,03	6,96	6,89	6,82	6,75	6,69	6,62	6,55	6,49
	Diesel	6,42	6,36	6,30	6,23	6,17	6,11	6,05	5,99	5,93	5,87	5,81	5,75	5,69	5,64
	HEV	5,18	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,78	4,73	4,68	4,63	4,59	4,54
	PHEV	5,18	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,78	4,73	4,68	4,63	4,59	4,54

Table C - 4: Germany fuel consumption evolution in L / 100 km per vehicles segment and powertrain technology. Profiles used for Fleet Model calculations.

		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Car FC	Gasoline	13,21	13,07	12,92	12,78	12,64	12,51	12,37	12,24	12,10	11,97	11,84	11,70	11,55	11,40	11,24	11,07	10,89	10,71	10,52
	Diesel	11,20	11,08	10,96	10,84	10,72	10,61	10,49	10,38	10,27	10,15	10,04	9,93	9,81	9,68	9,55	9,42	9,28	9,14	9,00
	HEV																			
	PHEV																			
SUV FC	Gasoline	14,31	14,15	14,00	13,84	13,69	13,54	13,40	13,25	13,11	12,96	12,82	12,67	12,51	12,35	12,17	11,98	11,79	11,59	11,39
	Diesel	12,13	12,00	11,87	11,74	11,62	11,49	11,36	11,24	11,12	11,00	10,88	10,75	10,62	10,49	10,35	10,20	10,05	9,90	9,74
	HEV																			
	PHEV																			
OLT FC	Gasoline	18,16	17,96	17,77	17,57	17,38	17,19	17,01	16,82	16,64	16,46	16,28	16,09	15,88	15,67	15,45	15,21	14,97	14,72	14,46
	Diesel	15,40	15,24	15,07	14,91	14,74	14,58	14,42	14,27	14,11	13,96	13,81	13,65	13,48	13,31	13,13	12,95	12,76	12,57	12,37
	HEV																			
	PHEV																			

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Car FC	Gasoline	10,32	10,12	9,92	9,72	9,52	9,33	9,11	8,89	8,69	8,48	8,28	8,09	7,89	7,70	7,51	7,33	7,15	7,14	7,14
	Diesel	8,85	8,70	8,55	8,40	8,25	8,10	7,91	7,73	7,55	7,37	7,20	7,03	6,86	6,69	6,53	6,37	6,21	6,21	6,20
	HEV					6,66	6,53	6,38	6,23	6,08	5,94	5,80	5,66	5,52	5,39	5,26	5,13	5,00	5,00	4,99
	PHEV					6,66	6,53	6,38	6,23	6,08	5,94	5,80	5,66	5,52	5,39	5,26	5,13	5,00	5,00	4,99
SUV FC	Gasoline	11,18	10,96	10,74	10,52	10,31	10,10	9,86	9,63	9,41	9,19	8,97	8,76	8,55	8,34	8,13	7,94	7,74	7,74	7,73
	Diesel	9,59	9,42	9,26	9,09	8,93	8,78	8,57	8,37	8,17	7,98	7,79	7,61	7,43	7,24	7,07	6,90	6,73	6,72	6,71
	HEV					7,22	7,07	6,90	6,74	6,58	6,43	6,28	6,13	5,98	5,84	5,69	5,56	5,42	5,41	5,41
	PHEV					7,22	7,07	6,90	6,74	6,58	6,43	6,28	6,13	5,98	5,84	5,69	5,56	5,42	5,41	5,41
OLT FC	Gasoline	14,19	13,91	13,63	13,36	13,08	12,82	12,52	12,23	11,94	11,66	11,39	11,12	10,85	10,58	10,33	10,07	9,83	9,82	9,81
	Diesel	12,17	11,96	11,75	11,54	11,34	11,14	10,88	10,62	10,37	10,13	9,89	9,66	9,43	9,20	8,97	8,75	8,54	8,53	8,52
	HEV					9,16	8,97	8,76	8,56	8,36	8,16	7,97	7,78	7,59	7,41	7,23	7,05	6,88	6,87	6,87
	PHEV					9,16	8,97	8,76	8,56	8,36	8,16	7,97	7,78	7,59	7,41	7,23	7,05	6,88	6,87	6,87

		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Car FC	Gasoline	7,06	6,99	6,92	6,85	6,79	6,72	6,65	6,58	6,52	6,45	6,39	6,32	6,26	6,20	6,14	6,08	6,01	5,95	5,89
	Diesel	6,14	6,08	6,02	5,96	5,90	5,84	5,78	5,72	5,66	5,61	5,55	5,50	5,44	5,39	5,33	5,28	5,23	5,17	5,12
	HEV	4,94	4,90	4,85	4,80	4,75	4,70	4,66	4,61	4,56	4,52	4,47	4,43	4,38	4,34	4,30	4,25	4,21	4,17	4,13
	PHEV	4,94	4,90	4,85	4,80	4,75	4,70	4,66	4,61	4,56	4,52	4,47	4,43	4,38	4,34	4,30	4,25	4,21	4,17	4,13
SUV FC	Gasoline	7,65	7,57	7,50	7,42	7,35	7,28	7,20	7,13	7,06	6,99	6,92	6,85	6,78	6,71	6,65	6,58	6,51	6,45	6,38
	Diesel	6,65	6,58	6,51	6,45	6,38	6,32	6,26	6,20	6,13	6,07	6,01	5,95	5,89	5,83	5,77	5,72	5,66	5,60	5,55
	HEV	5,36	5,30	5,25	5,20	5,14	5,09	5,04	4,99	4,94	4,89	4,84	4,79	4,75	4,70	4,65	4,61	4,56	4,51	4,47
	PHEV	5,36	5,30	5,25	5,20	5,14	5,09	5,04	4,99	4,94	4,89	4,84	4,79	4,75	4,70	4,65	4,61	4,56	4,51	4,47
OLT FC	Gasoline	9,71	9,61	9,52	9,42	9,33	9,23	9,14	9,05	8,96	8,87	8,78	8,69	8,61	8,52	8,44	8,35	8,27	8,19	8,10
	Diesel	8,44	8,35	8,27	8,19	8,10	8,02	7,94	7,86	7,79	7,71	7,63	7,55	7,48	7,40	7,33	7,26	7,18	7,11	7,04
	HEV	6,80	6,73	6,66	6,60	6,53	6,46	6,40	6,34	6,27	6,21	6,15	6,09	6,03	5,96	5,91	5,85	5,79	5,73	5,67
	PHEV	6,80	6,73	6,66	6,60	6,53	6,46	6,40	6,34	6,27	6,21	6,15	6,09	6,03	5,96	5,91	5,85	5,79	5,73	5,67

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	Gasoline	5,84	5,78	5,72	5,66	5,61	5,55	5,49	5,44	5,39	5,33	5,28	5,23	5,17	5,12
	Diesel	5,07	5,02	4,97	4,92	4,87	4,82	4,77	4,73	4,68	4,63	4,59	4,54	4,49	4,45
	HEV	4,09	4,04	4,00	3,96	3,92	3,88	3,85	3,81	3,77	3,73	3,69	3,66	3,62	3,58
	PHEV	4,09	4,04	4,00	3,96	3,92	3,88	3,85	3,81	3,77	3,73	3,69	3,66	3,62	3,58
SUV FC	Gasoline	6,32	6,26	6,19	6,13	6,07	6,01	5,95	5,89	5,83	5,77	5,72	5,66	5,60	5,55
	Diesel	5,49	5,44	5,38	5,33	5,27	5,22	5,17	5,12	5,07	5,02	4,97	4,92	4,87	4,82
	HEV	4,42	4,38	4,34	4,29	4,25	4,21	4,17	4,12	4,08	4,04	4,00	3,96	3,92	3,88
	PHEV	4,42	4,38	4,34	4,29	4,25	4,21	4,17	4,12	4,08	4,04	4,00	3,96	3,92	3,88
OLT FC	Gasoline	8,02	7,94	7,86	7,78	7,71	7,63	7,55	7,48	7,40	7,33	7,26	7,18	7,11	7,04
	Diesel	6,97	6,90	6,83	6,76	6,70	6,63	6,56	6,50	6,43	6,37	6,30	6,24	6,18	6,12
	HEV	5,62	5,56	5,50	5,45	5,39	5,34	5,29	5,23	5,18	5,13	5,08	5,03	4,98	4,93
	PHEV	5,62	5,56	5,50	5,45	5,39	5,34	5,29	5,23	5,18	5,13	5,08	5,03	4,98	4,93

Table C - 5: The Netherlands fuel consumption evolution in L / 100 km per vehicles segment and powertrain technology. Profiles used for Fleet Model calculations.

		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Car FC	Gasoline	11,86	11,73	11,61	11,48	11,35	11,23	11,11	10,99	10,87	10,75	10,63	10,51	10,37	10,22	10,06	9,90	9,72	9,54	9,35
	Diesel	9,90	9,79	9,68	9,58	9,47	9,37	9,27	9,17	9,07	8,97	8,87	8,77	8,66	8,55	8,43	8,31	8,18	8,05	7,92
	HEV																			
	PHEV																			
SUV FC	Gasoline	13,24	13,09	12,95	12,81	12,67	12,53	12,40	12,26	12,13	12,00	11,87	11,72	11,57	11,40	11,23	11,04	10,85	10,64	10,43
	Diesel	11,04	10,92	10,80	10,69	10,57	10,46	10,34	10,23	10,12	10,01	9,90	9,78	9,66	9,54	9,41	9,27	9,13	8,99	8,84
	HEV																			
	PHEV																			
OLT FC	Gasoline	16,71	16,52	16,34	16,17	15,99	15,82	15,64	15,47	15,31	15,14	14,97	14,79	14,60	14,39	14,17	13,94	13,69	13,43	13,16
	Diesel	13,94	13,78	13,63	13,49	13,34	13,19	13,05	12,91	12,77	12,63	12,49	12,35	12,19	12,04	11,87	11,70	11,52	11,34	11,15
	HEV																			
	PHEV																			

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Car FC	Gasoline	9,15	8,95	8,75	8,56	8,37	8,18	7,99	7,80	7,62	7,44	7,27	7,10	6,92	6,76	6,59	6,43	6,27	6,27	6,26
	Diesel	7,78	7,64	7,51	7,37	7,24	7,11	6,94	6,78	6,62	6,47	6,31	6,17	6,02	5,87	5,73	5,59	5,45	5,44	5,44
	HEV					5,86	5,73	5,59	5,46	5,33	5,21	5,09	4,97	4,85	4,73	4,61	4,50	4,39	4,39	4,38
	PHEV					5,86	5,73	5,59	5,46	5,33	5,21	5,09	4,97	4,85	4,73	4,61	4,50	4,39	4,39	4,38
SUV FC	Gasoline	10,21	9,99	9,77	9,55	9,34	9,13	8,92	8,71	8,50	8,31	8,11	7,92	7,73	7,54	7,36	7,18	7,00	6,99	6,99
	Diesel	8,69	8,53	8,38	8,23	8,08	7,93	7,75	7,57	7,39	7,22	7,05	6,88	6,71	6,55	6,39	6,23	6,08	6,08	6,07
	HEV					6,54	6,39	6,24	6,10	5,95	5,81	5,68	5,54	5,41	5,28	5,15	5,02	4,90	4,90	4,89
	PHEV					6,54	6,39	6,24	6,10	5,95	5,81	5,68	5,54	5,41	5,28	5,15	5,02	4,90	4,90	4,89
OLT FC	Gasoline	12,89	12,60	12,32	12,05	11,78	11,52	11,25	10,99	10,73	10,48	10,24	10,00	9,75	9,51	9,28	9,06	8,83	8,83	8,82
	Diesel	10,96	10,76	10,57	10,38	10,20	10,01	9,78	9,55	9,33	9,11	8,89	8,68	8,47	8,27	8,06	7,87	7,68	7,67	7,66
	HEV					8,25	8,07	7,88	7,69	7,51	7,34	7,16	7,00	6,83	6,66	6,50	6,34	6,18	6,18	6,17
	PHEV					8,25	8,07	7,88	7,69	7,51	7,34	7,16	7,00	6,83	6,66	6,50	6,34	6,18	6,18	6,17

		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Car FC	Gasoline	6,20	6,14	6,07	6,01	5,95	5,89	5,84	5,78	5,72	5,66	5,61	5,55	5,49	5,44	5,38	5,33	5,28	5,22	5,17
	Diesel	5,39	5,33	5,28	5,23	5,17	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,77	4,73	4,68	4,63	4,59	4,54	4,49
	HEV	4,34	4,30	4,25	4,21	4,17	4,13	4,08	4,04	4,00	3,96	3,92	3,88	3,85	3,81	3,77	3,73	3,69	3,66	3,62
	PHEV	4,34	4,30	4,25	4,21	4,17	4,13	4,08	4,04	4,00	3,96	3,92	3,88	3,85	3,81	3,77	3,73	3,69	3,66	3,62
SUV FC	Gasoline	6,92	6,85	6,78	6,71	6,64	6,58	6,51	6,45	6,38	6,32	6,26	6,19	6,13	6,07	6,01	5,95	5,89	5,83	5,77
	Diesel	6,01	5,95	5,89	5,83	5,77	5,72	5,66	5,60	5,55	5,49	5,44	5,38	5,33	5,27	5,22	5,17	5,12	5,07	5,02
	HEV	4,84	4,79	4,75	4,70	4,65	4,60	4,56	4,51	4,47	4,42	4,38	4,34	4,29	4,25	4,21	4,16	4,12	4,08	4,04
	PHEV	4,84	4,79	4,75	4,70	4,65	4,60	4,56	4,51	4,47	4,42	4,38	4,34	4,29	4,25	4,21	4,16	4,12	4,08	4,04
OLT FC	Gasoline	8,73	8,64	8,56	8,47	8,38	8,30	8,22	8,14	8,05	7,97	7,89	7,82	7,74	7,66	7,58	7,51	7,43	7,36	7,28
	Diesel	7,58	7,51	7,43	7,36	7,29	7,21	7,14	7,07	7,00	6,93	6,86	6,79	6,72	6,66	6,59	6,52	6,46	6,39	6,33
	HEV	6,11	6,05	5,99	5,93	5,87	5,81	5,75	5,70	5,64	5,58	5,53	5,47	5,42	5,36	5,31	5,26	5,20	5,15	5,10
	PHEV	6,11	6,05	5,99	5,93	5,87	5,81	5,75	5,70	5,64	5,58	5,53	5,47	5,42	5,36	5,31	5,26	5,20	5,15	5,10

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	Gasoline	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,77	4,73	4,68	4,63	4,58	4,54	4,49
	Diesel	4,45	4,40	4,36	4,32	4,27	4,23	4,19	4,15	4,11	4,06	4,02	3,98	3,94	3,90
	HEV	3,58	3,55	3,51	3,48	3,44	3,41	3,37	3,34	3,31	3,27	3,24	3,21	3,18	3,15
	PHEV	3,58	3,55	3,51	3,48	3,44	3,41	3,37	3,34	3,31	3,27	3,24	3,21	3,18	3,15
SUV FC	Gasoline	5,71	5,66	5,60	5,54	5,49	5,43	5,38	5,33	5,27	5,22	5,17	5,12	5,07	5,01
	Diesel	4,97	4,92	4,87	4,82	4,77	4,72	4,67	4,63	4,58	4,54	4,49	4,45	4,40	4,36
	HEV	4,00	3,96	3,92	3,88	3,84	3,80	3,77	3,73	3,69	3,65	3,62	3,58	3,55	3,51
	PHEV	4,00	3,96	3,92	3,88	3,84	3,80	3,77	3,73	3,69	3,65	3,62	3,58	3,55	3,51
OLT FC	Gasoline	7,21	7,14	7,07	7,00	6,93	6,86	6,79	6,72	6,65	6,59	6,52	6,46	6,39	6,33
	Diesel	6,27	6,20	6,14	6,08	6,02	5,96	5,90	5,84	5,78	5,72	5,67	5,61	5,55	5,50
	HEV	5,05	5,00	4,95	4,90	4,85	4,80	4,75	4,71	4,66	4,61	4,57	4,52	4,47	4,43
	PHEV	5,05	5,00	4,95	4,90	4,85	4,80	4,75	4,71	4,66	4,61	4,57	4,52	4,47	4,43

Table C - 6: Norway fuel consumption evolution in L / 100 km per vehicles segment and powertrain technology. Profiles used for Fleet Model calculations.

		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Car FC	Gasoline	12,83	12,69	12,55	12,41	12,28	12,15	12,01	11,88	11,75	11,63	11,50	11,36	11,21	11,05	10,88	10,70	10,51	10,31	10,11
	Diesel	10,70	10,59	10,47	10,36	10,24	10,13	10,02	9,91	9,80	9,70	9,59	9,48	9,36	9,24	9,12	8,98	8,85	8,71	8,56
	HEV																			
	PHEV																			
SUV FC	Gasoline	14,27	14,11	13,96	13,81	13,66	13,51	13,36	13,22	13,07	12,93	12,79	12,64	12,47	12,29	12,10	11,90	11,69	11,47	11,25
	Diesel	11,90	11,77	11,65	11,52	11,39	11,27	11,15	11,03	10,91	10,79	10,67	10,55	10,42	10,28	10,14	9,99	9,84	9,69	9,53
	HEV																			
	PHEV																			
OLT FC	Gasoline	18,40	18,20	18,01	17,81	17,62	17,42	17,23	17,05	16,86	16,68	16,50	16,30	16,08	15,85	15,61	15,35	15,08	14,80	14,50
	Diesel	15,35	15,19	15,02	14,86	14,69	14,54	14,38	14,22	14,07	13,91	13,76	13,60	13,43	13,26	13,08	12,89	12,69	12,49	12,29
	HEV																			
	PHEV																			

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Car FC	Gasoline	9,90	9,68	9,46	9,25	9,05	8,85	8,64	8,44	8,24	8,05	7,86	7,68	7,49	7,31	7,13	6,95	6,78	6,78	6,77
	Diesel	8,42	8,27	8,12	7,97	7,83	7,69	7,51	7,33	7,16	6,99	6,83	6,67	6,51	6,35	6,19	6,04	5,89	5,89	5,88
	HEV					6,33	6,19	6,05	5,91	5,77	5,63	5,50	5,37	5,24	5,11	4,99	4,87	4,75	4,74	4,74
	PHEV					6,33	6,19	6,05	5,91	5,77	5,63	5,50	5,37	5,24	5,11	4,99	4,87	4,75	4,74	4,74
SUV FC	Gasoline	11,01	10,77	10,53	10,29	10,07	9,84	9,61	9,39	9,17	8,95	8,74	8,54	8,33	8,13	7,93	7,74	7,55	7,54	7,53
	Diesel	9,36	9,19	9,03	8,87	8,71	8,55	8,35	8,16	7,97	7,78	7,60	7,42	7,24	7,06	6,89	6,72	6,56	6,55	6,54
	HEV					7,05	6,89	6,73	6,57	6,42	6,27	6,12	5,98	5,83	5,69	5,55	5,41	5,28	5,28	5,27
	PHEV					7,05	6,89	6,73	6,57	6,42	6,27	6,12	5,98	5,83	5,69	5,55	5,41	5,28	5,28	5,27
OLT FC	Gasoline	14,20	13,88	13,58	13,28	12,98	12,70	12,40	12,11	11,82	11,55	11,28	11,01	10,74	10,48	10,23	9,98	9,73	9,72	9,71
	Diesel	12,08	11,86	11,65	11,44	11,23	11,03	10,77	10,52	10,27	10,03	9,80	9,57	9,33	9,11	8,88	8,67	8,46	8,45	8,44
	HEV					9,09	8,89	8,68	8,48	8,28	8,08	7,89	7,71	7,52	7,34	7,16	6,98	6,81	6,81	6,80
	PHEV					9,09	8,89	8,68	8,48	8,28	8,08	7,89	7,71	7,52	7,34	7,16	6,98	6,81	6,81	6,80

		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Car FC	Gasoline	6,70	6,64	6,57	6,50	6,44	6,37	6,31	6,25	6,19	6,12	6,06	6,00	5,94	5,88	5,82	5,77	5,71	5,65	5,59
	Diesel	5,82	5,77	5,71	5,65	5,59	5,54	5,48	5,43	5,37	5,32	5,27	5,21	5,16	5,11	5,06	5,01	4,96	4,91	4,86
	HEV	4,69	4,65	4,60	4,55	4,51	4,46	4,42	4,37	4,33	4,29	4,24	4,20	4,16	4,12	4,08	4,04	4,00	3,96	3,92
	PHEV	4,69	4,65	4,60	4,55	4,51	4,46	4,42	4,37	4,33	4,29	4,24	4,20	4,16	4,12	4,08	4,04	4,00	3,96	3,92
SUV FC	Gasoline	7,46	7,38	7,31	7,23	7,16	7,09	7,02	6,95	6,88	6,81	6,74	6,68	6,61	6,54	6,48	6,41	6,35	6,29	6,22
	Diesel	6,48	6,41	6,35	6,29	6,22	6,16	6,10	6,04	5,98	5,92	5,86	5,80	5,74	5,68	5,63	5,57	5,52	5,46	5,41
	HEV	5,22	5,17	5,12	5,06	5,01	4,96	4,91	4,86	4,82	4,77	4,72	4,67	4,63	4,58	4,53	4,49	4,44	4,40	4,36
	PHEV	5,22	5,17	5,12	5,06	5,01	4,96	4,91	4,86	4,82	4,77	4,72	4,67	4,63	4,58	4,53	4,49	4,44	4,40	4,36
OLT FC	Gasoline	9,62	9,52	9,42	9,33	9,24	9,14	9,05	8,96	8,87	8,78	8,70	8,61	8,52	8,44	8,35	8,27	8,19	8,11	8,02
	Diesel	8,36	8,27	8,19	8,11	8,03	7,95	7,87	7,79	7,71	7,63	7,56	7,48	7,41	7,33	7,26	7,19	7,11	7,04	6,97
	HEV	6,73	6,66	6,60	6,53	6,47	6,40	6,34	6,27	6,21	6,15	6,09	6,03	5,97	5,91	5,85	5,79	5,73	5,67	5,62
	PHEV	6,73	6,66	6,60	6,53	6,47	6,40	6,34	6,27	6,21	6,15	6,09	6,03	5,97	5,91	5,85	5,79	5,73	5,67	5,62

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	Gasoline	5,54	5,48	5,43	5,37	5,32	5,27	5,21	5,16	5,11	5,06	5,01	4,96	4,91	4,86
	Diesel	4,81	4,76	4,72	4,67	4,62	4,58	4,53	4,48	4,44	4,40	4,35	4,31	4,26	4,22
	HEV	3,88	3,84	3,80	3,76	3,72	3,69	3,65	3,61	3,58	3,54	3,51	3,47	3,44	3,40
	PHEV	3,88	3,84	3,80	3,76	3,72	3,69	3,65	3,61	3,58	3,54	3,51	3,47	3,44	3,40
SUV FC	Gasoline	6,16	6,10	6,04	5,98	5,92	5,86	5,80	5,74	5,68	5,63	5,57	5,52	5,46	5,41
	Diesel	5,35	5,30	5,25	5,19	5,14	5,09	5,04	4,99	4,94	4,89	4,84	4,79	4,74	4,70
	HEV	4,31	4,27	4,23	4,18	4,14	4,10	4,06	4,02	3,98	3,94	3,90	3,86	3,82	3,78
	PHEV	4,31	4,27	4,23	4,18	4,14	4,10	4,06	4,02	3,98	3,94	3,90	3,86	3,82	3,78
OLT FC	Gasoline	7,94	7,87	7,79	7,71	7,63	7,56	7,48	7,40	7,33	7,26	7,18	7,11	7,04	6,97
	Diesel	6,90	6,83	6,77	6,70	6,63	6,56	6,50	6,43	6,37	6,31	6,24	6,18	6,12	6,06
	HEV	5,56	5,51	5,45	5,40	5,34	5,29	5,24	5,18	5,13	5,08	5,03	4,98	4,93	4,88
	PHEV	5,56	5,51	5,45	5,40	5,34	5,29	5,24	5,18	5,13	5,08	5,03	4,98	4,93	4,88

Table C - 7: Spain fuel consumption evolution in L / 100 km per vehicles segment and powertrain technology. Profiles used for Fleet Model calculations.

		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Car FC	Gasoline	11,97	11,84	11,71	11,58	11,45	11,33	11,21	11,09	10,96	10,85	10,73	10,60	10,47	10,33	10,18	10,03	9,86	9,70	9,53
	Diesel	10,15	10,04	9,93	9,82	9,72	9,61	9,51	9,40	9,30	9,20	9,10	8,99	8,89	8,77	8,66	8,53	8,41	8,28	8,15
	HEV																			
	PHEV																			
SUV FC	Gasoline	13,36	13,21	13,07	12,92	12,78	12,64	12,51	12,37	12,24	12,10	11,97	11,83	11,68	11,53	11,36	11,19	11,01	10,82	10,63
	Diesel	11,33	11,21	11,08	10,96	10,84	10,73	10,61	10,49	10,38	10,27	10,15	10,04	9,92	9,79	9,66	9,52	9,39	9,24	9,10
	HEV																			
	PHEV																			
OLT FC	Gasoline	16,85	16,67	16,49	16,31	16,13	15,96	15,78	15,61	15,44	15,27	15,11	14,93	14,74	14,54	14,34	14,12	13,89	13,66	13,42
	Diesel	14,30	14,14	13,99	13,83	13,68	13,53	13,39	13,24	13,10	12,96	12,81	12,67	12,51	12,35	12,19	12,02	11,84	11,66	11,48
	HEV																			
	PHEV																			

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Car FC	Gasoline	9,35	9,17	8,98	8,80	8,62	8,45	8,25	8,06	7,87	7,68	7,50	7,33	7,15	6,97	6,80	6,64	6,48	6,47	6,46
	Diesel	8,02	7,88	7,74	7,61	7,47	7,34	7,17	7,00	6,84	6,68	6,52	6,37	6,21	6,06	5,91	5,77	5,63	5,62	5,62
	HEV					6,04	5,91	5,78	5,64	5,51	5,38	5,25	5,13	5,00	4,88	4,76	4,65	4,53	4,53	4,52
	PHEV					6,04	5,91	5,78	5,64	5,51	5,38	5,25	5,13	5,00	4,88	4,76	4,65	4,53	4,53	4,52
SUV FC	Gasoline	10,43	10,23	10,03	9,82	9,62	9,43	9,21	8,99	8,78	8,58	8,37	8,18	7,98	7,78	7,59	7,41	7,23	7,22	7,21
	Diesel	8,95	8,80	8,64	8,49	8,34	8,19	8,00	7,81	7,63	7,45	7,28	7,11	6,93	6,76	6,60	6,44	6,28	6,27	6,27
	HEV					6,74	6,60	6,45	6,29	6,15	6,00	5,86	5,72	5,59	5,45	5,32	5,19	5,06	5,05	5,05
	PHEV					6,74	6,60	6,45	6,29	6,15	6,00	5,86	5,72	5,59	5,45	5,32	5,19	5,06	5,05	5,05
OLT FC	Gasoline	13,17	12,91	12,65	12,40	12,14	11,90	11,62	11,35	11,08	10,82	10,57	10,32	10,07	9,82	9,58	9,35	9,12	9,11	9,10
	Diesel	11,29	11,10	10,90	10,71	10,52	10,34	10,10	9,86	9,63	9,40	9,18	8,97	8,75	8,53	8,33	8,12	7,93	7,92	7,91
	HEV					8,50	8,33	8,13	7,94	7,76	7,58	7,40	7,22	7,05	6,88	6,71	6,54	6,39	6,38	6,37
	PHEV					8,50	8,33	8,13	7,94	7,76	7,58	7,40	7,22	7,05	6,88	6,71	6,54	6,39	6,38	6,37

		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Car FC	Gasoline	6,40	6,34	6,27	6,21	6,15	6,09	6,02	5,96	5,90	5,85	5,79	5,73	5,67	5,62	5,56	5,50	5,45	5,39	5,34
	Diesel	5,56	5,50	5,45	5,39	5,34	5,29	5,23	5,18	5,13	5,08	5,03	4,98	4,93	4,88	4,83	4,78	4,73	4,69	4,64
	HEV	4,48	4,43	4,39	4,35	4,30	4,26	4,22	4,18	4,13	4,09	4,05	4,01	3,97	3,93	3,89	3,85	3,81	3,78	3,74
	PHEV	4,48	4,43	4,39	4,35	4,30	4,26	4,22	4,18	4,13	4,09	4,05	4,01	3,97	3,93	3,89	3,85	3,81	3,78	3,74
SUV FC	Gasoline	7,14	7,07	7,00	6,93	6,86	6,79	6,72	6,66	6,59	6,52	6,46	6,39	6,33	6,27	6,20	6,14	6,08	6,02	5,96
	Diesel	6,21	6,14	6,08	6,02	5,96	5,90	5,84	5,78	5,73	5,67	5,61	5,56	5,50	5,45	5,39	5,34	5,28	5,23	5,18
	HEV	5,00	4,95	4,90	4,85	4,80	4,75	4,71	4,66	4,61	4,57	4,52	4,48	4,43	4,39	4,34	4,30	4,26	4,21	4,17
	PHEV	5,00	4,95	4,90	4,85	4,80	4,75	4,71	4,66	4,61	4,57	4,52	4,48	4,43	4,39	4,34	4,30	4,26	4,21	4,17
OLT FC	Gasoline	9,01	8,92	8,83	8,74	8,66	8,57	8,48	8,40	8,32	8,23	8,15	8,07	7,99	7,91	7,83	7,75	7,67	7,60	7,52
	Diesel	7,83	7,75	7,67	7,60	7,52	7,45	7,37	7,30	7,23	7,15	7,08	7,01	6,94	6,87	6,80	6,73	6,67	6,60	6,53
	HEV	6,31	6,25	6,18	6,12	6,06	6,00	5,94	5,88	5,82	5,76	5,71	5,65	5,59	5,54	5,48	5,43	5,37	5,32	5,26
	PHEV	6,31	6,25	6,18	6,12	6,06	6,00	5,94	5,88	5,82	5,76	5,71	5,65	5,59	5,54	5,48	5,43	5,37	5,32	5,26

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	Gasoline	5,29	5,23	5,18	5,13	5,08	5,03	4,98	4,93	4,88	4,83	4,78	4,73	4,69	4,64
	Diesel	4,59	4,55	4,50	4,46	4,41	4,37	4,32	4,28	4,24	4,20	4,15	4,11	4,07	4,03
	HEV	3,70	3,66	3,63	3,59	3,56	3,52	3,48	3,45	3,41	3,38	3,35	3,31	3,28	3,25
	PHEV	3,70	3,66	3,63	3,59	3,56	3,52	3,48	3,45	3,41	3,38	3,35	3,31	3,28	3,25
SUV FC	Gasoline	5,90	5,84	5,78	5,73	5,67	5,61	5,56	5,50	5,44	5,39	5,34	5,28	5,23	5,18
	Diesel	5,13	5,08	5,02	4,97	4,92	4,88	4,83	4,78	4,73	4,68	4,64	4,59	4,54	4,50
	HEV	4,13	4,09	4,05	4,01	3,97	3,93	3,89	3,85	3,81	3,77	3,74	3,70	3,66	3,62
	PHEV	4,13	4,09	4,05	4,01	3,97	3,93	3,89	3,85	3,81	3,77	3,74	3,70	3,66	3,62
OLT FC	Gasoline	7,45	7,37	7,30	7,22	7,15	7,08	7,01	6,94	6,87	6,80	6,73	6,67	6,60	6,53
	Diesel	6,47	6,40	6,34	6,28	6,21	6,15	6,09	6,03	5,97	5,91	5,85	5,79	5,73	5,68
	HEV	5,21	5,16	5,11	5,06	5,01	4,96	4,91	4,86	4,81	4,76	4,71	4,67	4,62	4,57
	PHEV	5,21	5,16	5,11	5,06	5,01	4,96	4,91	4,86	4,81	4,76	4,71	4,67	4,62	4,57

Table C - 8: The United Kingdom fuel consumption evolution in L / 100 km per vehicles segment and powertrain technology. Profiles used for Fleet Model calculations.

		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Car FC	Gasoline	12,96	12,82	12,68	12,54	12,40	12,27	12,14	12,00	11,87	11,74	11,62	11,48	11,34	11,18	11,02	10,86	10,68	10,50	10,32
	Diesel	10,99	10,87	10,75	10,64	10,52	10,41	10,29	10,18	10,07	9,96	9,85	9,74	9,62	9,50	9,37	9,24	9,11	8,97	8,83
	HEV																			
	PHEV																			
SUV FC	Gasoline	14,03	13,88	13,73	13,58	13,43	13,28	13,14	13,00	12,86	12,72	12,58	12,43	12,27	12,11	11,93	11,75	11,57	11,37	11,17
	Diesel	11,90	11,77	11,64	11,52	11,39	11,27	11,15	11,02	10,90	10,79	10,67	10,55	10,42	10,29	10,15	10,01	9,86	9,71	9,56
	HEV																			
	PHEV																			
OLT FC	Gasoline	18,07	17,87	17,67	17,48	17,29	17,10	16,92	16,73	16,55	16,37	16,19	16,00	15,80	15,59	15,37	15,13	14,89	14,64	14,38
	Diesel	15,32	15,16	14,99	14,83	14,67	14,51	14,35	14,19	14,04	13,89	13,74	13,58	13,41	13,24	13,07	12,88	12,70	12,50	12,31
	HEV																			
	PHEV																			

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Car FC	Gasoline	10,12	9,93	9,73	9,53	9,34	9,15	8,93	8,73	8,52	8,32	8,13	7,94	7,74	7,55	7,37	7,19	7,01	7,01	7,00
	Diesel	8,68	8,53	8,38	8,24	8,09	7,95	7,76	7,58	7,40	7,23	7,06	6,89	6,73	6,56	6,40	6,25	6,09	6,09	6,08
	HEV					6,54	6,40	6,25	6,11	5,96	5,82	5,69	5,55	5,42	5,29	5,16	5,03	4,91	4,90	4,90
	PHEV					6,54	6,40	6,25	6,11	5,96	5,82	5,69	5,55	5,42	5,29	5,16	5,03	4,91	4,90	4,90
SUV FC	Gasoline	10,96	10,75	10,53	10,32	10,11	9,91	9,67	9,45	9,23	9,01	8,80	8,59	8,38	8,18	7,98	7,78	7,59	7,59	7,58
	Diesel	9,40	9,24	9,08	8,92	8,76	8,61	8,40	8,21	8,02	7,83	7,64	7,47	7,28	7,11	6,93	6,76	6,60	6,59	6,58
	HEV					7,08	6,93	6,77	6,61	6,46	6,31	6,16	6,01	5,87	5,72	5,58	5,45	5,32	5,31	5,31
	PHEV					7,08	6,93	6,77	6,61	6,46	6,31	6,16	6,01	5,87	5,72	5,58	5,45	5,32	5,31	5,31
OLT FC	Gasoline	14,11	13,84	13,56	13,29	13,02	12,75	12,46	12,16	11,88	11,60	11,33	11,06	10,79	10,53	10,27	10,02	9,78	9,77	9,76
	Diesel	12,10	11,90	11,69	11,48	11,28	11,08	10,82	10,57	10,32	10,08	9,84	9,61	9,38	9,15	8,93	8,71	8,50	8,49	8,48
	HEV					9,11	8,93	8,72	8,51	8,31	8,12	7,93	7,74	7,55	7,37	7,19	7,02	6,84	6,84	6,83
	PHEV					9,11	8,93	8,72	8,51	8,31	8,12	7,93	7,74	7,55	7,37	7,19	7,02	6,84	6,84	6,83

		2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Car FC	Gasoline	6,93	6,86	6,79	6,72	6,66	6,59	6,52	6,46	6,39	6,33	6,27	6,20	6,14	6,08	6,02	5,96	5,90	5,84	5,78
	Diesel	6,02	5,96	5,90	5,84	5,78	5,73	5,67	5,61	5,56	5,50	5,45	5,39	5,34	5,28	5,23	5,18	5,13	5,08	5,02
	HEV	4,85	4,80	4,75	4,71	4,66	4,61	4,57	4,52	4,48	4,43	4,39	4,34	4,30	4,26	4,21	4,17	4,13	4,09	4,05
	PHEV	4,85	4,80	4,75	4,71	4,66	4,61	4,57	4,52	4,48	4,43	4,39	4,34	4,30	4,26	4,21	4,17	4,13	4,09	4,05
SUV FC	Gasoline	7,50	7,43	7,35	7,28	7,21	7,14	7,06	6,99	6,92	6,85	6,79	6,72	6,65	6,58	6,52	6,45	6,39	6,32	6,26
	Diesel	6,52	6,45	6,39	6,33	6,26	6,20	6,14	6,08	6,02	5,96	5,90	5,84	5,78	5,72	5,66	5,61	5,55	5,50	5,44
	HEV	5,25	5,20	5,15	5,10	5,05	4,99	4,94	4,90	4,85	4,80	4,75	4,70	4,66	4,61	4,56	4,52	4,47	4,43	4,38
	PHEV	5,25	5,20	5,15	5,10	5,05	4,99	4,94	4,90	4,85	4,80	4,75	4,70	4,66	4,61	4,56	4,52	4,47	4,43	4,38
OLT FC	Gasoline	9,66	9,56	9,47	9,37	9,28	9,19	9,10	9,00	8,91	8,82	8,74	8,65	8,56	8,48	8,39	8,31	8,23	8,14	8,06
	Diesel	8,39	8,31	8,23	8,14	8,06	7,98	7,90	7,82	7,75	7,67	7,59	7,52	7,44	7,37	7,29	7,22	7,15	7,08	7,00
	HEV	6,76	6,69	6,63	6,56	6,50	6,43	6,37	6,30	6,24	6,18	6,12	6,05	5,99	5,93	5,87	5,82	5,76	5,70	5,64
	PHEV	6,76	6,69	6,63	6,56	6,50	6,43	6,37	6,30	6,24	6,18	6,12	6,05	5,99	5,93	5,87	5,82	5,76	5,70	5,64

		2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	Gasoline	5,73	5,67	5,61	5,56	5,50	5,44	5,39	5,34	5,28	5,23	5,18	5,13	5,07	5,02
	Diesel	4,97	4,92	4,88	4,83	4,78	4,73	4,68	4,64	4,59	4,54	4,50	4,45	4,41	4,37
	HEV	4,01	3,97	3,93	3,89	3,85	3,81	3,77	3,74	3,70	3,66	3,62	3,59	3,55	3,52
	PHEV	4,01	3,97	3,93	3,89	3,85	3,81	3,77	3,74	3,70	3,66	3,62	3,59	3,55	3,52
SUV FC	Gasoline	6,20	6,14	6,08	6,01	5,95	5,89	5,84	5,78	5,72	5,66	5,61	5,55	5,49	5,44
	Diesel	5,39	5,33	5,28	5,23	5,17	5,12	5,07	5,02	4,97	4,92	4,87	4,82	4,77	4,73
	HEV	4,34	4,30	4,25	4,21	4,17	4,13	4,09	4,04	4,00	3,96	3,92	3,89	3,85	3,81
	PHEV	4,34	4,30	4,25	4,21	4,17	4,13	4,09	4,04	4,00	3,96	3,92	3,89	3,85	3,81
OLT FC	Gasoline	7,98	7,90	7,82	7,74	7,67	7,59	7,51	7,44	7,36	7,29	7,22	7,15	7,07	7,00
	Diesel	6,93	6,87	6,80	6,73	6,66	6,59	6,53	6,46	6,40	6,33	6,27	6,21	6,15	6,09
	HEV	5,59	5,53	5,48	5,42	5,37	5,31	5,26	5,21	5,16	5,10	5,05	5,00	4,95	4,90
	PHEV	5,59	5,53	5,48	5,42	5,37	5,31	5,26	5,21	5,16	5,10	5,05	5,00	4,95	4,90

Table C - 9: Fleet Model input energy consumption profile for electric vehicle powertrains in kWh / km.

		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Car FC	PHEV		0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21	0,20
	BEV		0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21	0,20
	FCEV		0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,22	0,21	0,21	0,21	0,21	0,20
SUV FC	PHEV		0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,28	0,28	0,28	0,28	0,27	0,27	0,27	0,26	0,26
	BEV		0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,28	0,28	0,28	0,28	0,27	0,27	0,27	0,26	0,26
	FCEV		0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,28	0,28	0,28	0,28	0,27	0,27	0,27	0,26	0,26
OLT FC	PHEV		0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,28	0,28	0,28	0,28	0,27	0,27	0,27	0,26	0,26
	BEV		0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,28	0,28	0,28	0,28	0,27	0,27	0,27	0,26	0,26
	FCEV		0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,29	0,28	0,28	0,28	0,28	0,27	0,27	0,27	0,26	0,26

		2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Car FC	PHEV	0,20	0,20	0,20	0,20	0,19	0,19	0,19	0,19	0,19	0,18	0,18	0,18	0,18	0,18	0,18	0,17	0,17	0,17	0,17	0,17	0,17	0,16
	BEV	0,20	0,20	0,20	0,20	0,19	0,19	0,19	0,19	0,19	0,18	0,18	0,18	0,18	0,18	0,18	0,17	0,17	0,17	0,17	0,17	0,17	0,16
	FCEV	0,20	0,20	0,20	0,20	0,19	0,19	0,19	0,19	0,19	0,18	0,18	0,18	0,18	0,18	0,18	0,17	0,17	0,17	0,17	0,17	0,17	0,16
SUV FC	PHEV	0,26	0,26	0,25	0,25	0,25	0,25	0,24	0,24	0,24	0,24	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,21	0,21	0,21
	BEV	0,26	0,26	0,25	0,25	0,25	0,25	0,24	0,24	0,24	0,24	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,21	0,21	0,21
	FCEV	0,26	0,26	0,25	0,25	0,25	0,25	0,24	0,24	0,24	0,24	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,21	0,21	0,21
OLT FC	PHEV	0,26	0,26	0,25	0,25	0,25	0,25	0,24	0,24	0,24	0,24	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,21	0,21	0,21
	BEV	0,26	0,26	0,25	0,25	0,25	0,25	0,24	0,24	0,24	0,24	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,21	0,21	0,21
	FCEV	0,26	0,26	0,25	0,25	0,25	0,25	0,24	0,24	0,24	0,24	0,23	0,23	0,23	0,23	0,23	0,22	0,22	0,22	0,22	0,21	0,21	0,21

Appendix D: Electricity grid generation mix in major European countries analyzed and projected trend

All input data is retrieved from the European Commission and IEA sources.

Table D - 1: Electricity grid generation mix evolution in previous years in France for each source of energy considered in the Fleet Model.

Market Generation Mix by Source Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Solid fossil fuels, peat and products, oil shale & oil sands	4,78%	3,98%	4,29%	4,02%	4,04%	4,10%	3,11%	3,75%	4,10%	1,97%	2,05%	1,83%	2,25%
of which hard coal	4,78%	3,98%	4,29%	4,02%	4,04%	4,10%	3,11%	3,75%	4,10%	1,97%	2,05%	1,83%	2,25%
of which brown coal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Oil & petroleum products	1,38%	1,24%	1,08%	0,93%	0,88%	0,97%	1,30%	1,27%	1,10%	1,12%	1,15%	1,22%	1,32%
Natural gas & manufactured gas	4,56%	4,40%	4,52%	4,40%	4,27%	4,69%	5,58%	4,45%	3,60%	2,75%	4,11%	6,56%	7,63%
of which natural gas	4,00%	3,79%	3,86%	3,82%	3,83%	4,17%	5,15%	3,98%	3,17%	2,30%	3,65%	6,20%	7,20%
Nuclear	78,38%	78,31%	77,22%	76,62%	76,49%	75,29%	77,22%	74,40%	72,91%	76,36%	75,62%	71,51%	70,95%
Renewables & biofuels	10,62%	11,79%	12,57%	13,69%	13,93%	14,58%	12,42%	15,72%	17,91%	17,42%	16,67%	18,45%	17,41%
Hydro	9,78%	10,74%	11,11%	11,92%	11,57%	11,86%	8,86%	11,31%	13,24%	12,17%	10,44%	11,65%	9,82%
Wind	0,17%	0,38%	0,71%	0,99%	1,48%	1,75%	2,11%	2,62%	2,77%	3,03%	3,69%	3,81%	4,40%
Solid biofuels & renewable wastes	0,51%	0,50%	0,55%	0,57%	0,61%	0,60%	0,74%	0,71%	0,65%	0,71%	0,79%	1,00%	1,00%
Biogases	0,08%	0,09%	0,11%	0,12%	0,16%	0,18%	0,20%	0,23%	0,27%	0,29%	0,32%	0,35%	0,37%
Liquid biofuels	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Solar	0,00%	0,00%	0,00%	0,01%	0,03%	0,11%	0,41%	0,77%	0,89%	1,12%	1,34%	1,54%	1,70%
Geothermal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%	0,02%	0,01%	0,02%	0,02%	0,02%
Tide, Wave & Ocean	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,08%	0,07%	0,08%	0,08%	0,09%	0,09%
Wastes non-RES	0,29%	0,28%	0,32%	0,33%	0,39%	0,36%	0,38%	0,40%	0,38%	0,38%	0,39%	0,43%	0,44%
Other	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Table D - 2: Electricity grid generation mix evolution in previous years in Germany for each source of energy considered in the Fleet Model.

Market Generation Mix by Source Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Solid fossil fuels, peat and products, oil shale & oil sands	46,52%	45,45%	46,55%	43,12%	42,70%	41,69%	42,97%	44,14%	45,25%	43,85%	42,20%	40,44%	37,10%
of which hard coal	21,65%	21,69%	22,26%	19,52%	18,17%	18,56%	18,40%	18,54%	19,98%	18,95%	18,25%	17,34%	14,35%
of which brown coal	24,64%	23,53%	24,00%	23,31%	24,29%	22,91%	24,31%	25,33%	24,97%	24,64%	23,67%	22,85%	22,53%
Oil & petroleum products	1,94%	1,72%	1,57%	1,52%	1,70%	1,39%	1,17%	1,21%	1,13%	0,90%	0,96%	0,90%	0,85%
Natural gas & manufactured gas	13,50%	13,57%	14,22%	15,75%	14,98%	16,00%	15,90%	13,94%	12,49%	11,63%	11,55%	14,48%	15,12%
of which natural gas	11,95%	12,07%	12,47%	14,15%	13,84%	14,33%	14,28%	12,36%	10,79%	9,95%	9,77%	12,71%	13,45%
Nuclear	26,33%	26,31%	22,02%	23,27%	22,73%	22,29%	17,68%	15,84%	15,27%	15,52%	14,23%	13,08%	11,71%
Renewables & biofuels	11,19%	12,33%	14,92%	15,56%	16,93%	17,63%	21,22%	23,82%	24,83%	26,91%	29,96%	29,96%	34,10%
Hydro	4,27%	4,21%	4,40%	4,15%	4,16%	4,34%	3,85%	4,44%	4,52%	4,07%	3,86%	4,04%	4,01%
Wind	4,40%	4,83%	6,22%	6,36%	6,51%	5,99%	8,00%	8,07%	8,12%	9,17%	12,28%	12,14%	16,21%
Solid biofuels & renewable wastes	1,68%	1,96%	2,03%	2,15%	2,33%	2,46%	2,63%	2,71%	2,68%	2,87%	2,60%	2,58%	2,55%
Biogases	0,62%	0,86%	1,64%	2,03%	2,53%	2,76%	3,47%	4,34%	4,59%	4,97%	5,13%	5,21%	5,20%
Liquid biofuels	0,02%	0,11%	0,15%	0,17%	0,29%	0,22%	0,06%	0,06%	0,04%	0,06%	0,07%	0,08%	0,07%
Solar	0,21%	0,35%	0,48%	0,69%	1,11%	1,86%	3,21%	4,20%	4,87%	5,76%	6,00%	5,89%	6,04%
Geothermal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,01%	0,02%	0,02%	0,03%	0,02%
Tide, Wave & Ocean	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wastes non-RES	0,53%	0,61%	0,71%	0,79%	0,95%	1,01%	1,05%	1,04%	1,03%	1,19%	1,09%	1,13%	1,12%
Other	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Table D - 3: Electricity grid generation mix evolution in previous years in the Netherlands for each source of energy considered in the Fleet Model.

Market Generation Mix by Source Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Solid fossil fuels, peat and products, oil shale & oil sands	23,58%	24,05%	23,73%	21,86%	21,38%	18,96%	18,79%	23,49%	24,25%	28,57%	35,72%	31,91%	26,70%
of which hard coal	23,58%	24,05%	23,73%	21,86%	21,38%	18,96%	18,79%	23,49%	24,25%	28,57%	35,72%	31,91%	26,70%
of which brown coal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Oil & petroleum products	2,27%	2,12%	2,11%	1,92%	1,31%	1,05%	1,24%	1,03%	1,19%	1,85%	1,21%	1,11%	1,01%
Natural gas & manufactured gas	61,23%	60,71%	61,49%	62,09%	62,70%	65,94%	63,98%	57,88%	58,12%	52,76%	45,48%	49,21%	53,06%
of which natural gas	57,80%	57,90%	58,11%	58,99%	60,65%	63,24%	61,04%	54,87%	55,24%	49,92%	42,89%	46,84%	50,71%
Nuclear	4,01%	3,52%	4,00%	3,88%	3,74%	3,33%	3,64%	3,80%	2,85%	3,96%	3,70%	3,44%	2,90%
Renewables & biofuels	7,47%	8,16%	7,22%	8,87%	9,54%	9,40%	10,82%	12,11%	11,93%	11,28%	12,41%	12,84%	14,88%
Hydro	0,09%	0,11%	0,10%	0,09%	0,09%	0,09%	0,05%	0,10%	0,11%	0,11%	0,08%	0,09%	0,05%
Wind	2,07%	2,77%	3,27%	3,97%	4,03%	3,35%	4,48%	4,83%	5,54%	5,62%	6,85%	7,10%	9,02%
Solid biofuels & renewable wastes	3,52%	3,19%	3,21%	3,70%	4,51%	5,00%	5,28%	6,01%	4,90%	3,88%	3,54%	3,40%	3,14%
Biogases	0,30%	0,37%	0,49%	0,68%	0,81%	0,86%	0,91%	0,98%	0,97%	0,97%	0,94%	0,86%	0,79%
Liquid biofuels	1,45%	1,68%	0,12%	0,40%	0,07%	0,05%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Solar	0,04%	0,04%	0,04%	0,04%	0,04%	0,05%	0,09%	0,18%	0,40%	0,70%	1,01%	1,39%	1,88%
Geothermal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Tide, Wave & Ocean	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wastes non-RES	1,43%	1,44%	1,44%	1,37%	1,33%	1,31%	1,52%	1,70%	1,67%	1,58%	1,48%	1,48%	1,44%
Other	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Table D - 4: Electricity grid generation mix evolution in previous years in Norway for each source of energy considered in the Fleet Model.

Market Generation Mix by Source Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Solid fossil fuels, peat and products, oil shale & oil sands	0,10%	0,11%	0,10%	0,09%	0,07%	0,11%	0,11%	0,11%	0,11%	0,11%	0,10%	0,10%	0,09%
of which hard coal	0,10%	0,11%	0,10%	0,09%	0,07%	0,11%	0,11%	0,11%	0,11%	0,11%	0,10%	0,10%	0,09%
of which brown coal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Oil & petroleum products	0,02%	0,02%	0,02%	0,02%	0,02%	0,03%	0,03%	0,02%	0,03%	0,02%	0,02%	0,02%	0,02%
Natural gas & manufactured gas	0,27%	0,39%	1,25%	2,06%	3,21%	3,94%	3,18%	1,78%	1,83%	1,84%	1,80%	1,74%	1,75%
of which natural gas	0,27%	0,39%	1,25%	2,06%	3,21%	3,94%	3,18%	1,78%	1,83%	1,84%	1,80%	1,74%	1,75%
Nuclear	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Renewables & biofuels	99,55%	99,40%	98,55%	97,74%	96,61%	95,77%	96,51%	97,91%	97,72%	97,73%	97,75%	97,88%	97,87%
Hydro	98,98%	98,60%	97,67%	96,87%	95,73%	94,86%	95,30%	96,71%	96,17%	96,13%	95,98%	96,43%	95,93%
Wind	0,36%	0,52%	0,65%	0,63%	0,74%	0,71%	1,01%	1,05%	1,41%	1,56%	1,74%	1,42%	1,91%
Solid biofuels & renewable wastes	0,21%	0,27%	0,24%	0,23%	0,13%	0,20%	0,20%	0,14%	0,14%	0,03%	0,03%	0,03%	0,03%
Biogases	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Liquid biofuels	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Solar	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Geothermal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Tide, Wave & Ocean	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wastes non-RES	0,07%	0,08%	0,08%	0,09%	0,08%	0,16%	0,18%	0,17%	0,31%	0,30%	0,33%	0,26%	0,27%
Other	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Table D - 5: Electricity grid generation mix evolution in previous years in Spain for each source of energy considered in the Fleet Model.

Market Generation Mix													
by Source Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Solid fossil fuels, peat and products, oil shale & oil sands	27,35%	22,31%	23,89%	15,54%	12,20%	8,41%	14,98%	18,52%	13,98%	15,72%	18,30%	13,26%	16,37%
of which hard coal	23,88%	19,47%	21,14%	14,48%	11,56%	7,98%	13,61%	17,50%	13,20%	14,66%	17,15%	12,59%	15,44%
of which brown coal	3,47%	2,84%	2,75%	1,06%	0,64%	0,43%	1,36%	1,02%	0,79%	1,05%	1,15%	0,67%	0,93%
Oil & petroleum products	8,45%	7,97%	6,07%	5,74%	6,54%	5,50%	5,00%	5,15%	4,82%	5,07%	6,14%	6,16%	5,72%
Natural gas & manufactured gas	27,92%	30,69%	31,53%	38,94%	36,96%	31,80%	29,51%	24,96%	20,63%	17,49%	19,17%	19,60%	23,68%
of which natural gas	27,33%	30,28%	31,11%	38,54%	36,61%	31,47%	29,12%	24,65%	20,14%	16,96%	18,70%	19,23%	23,23%
Nuclear	19,90%	20,10%	18,08%	18,81%	17,93%	20,57%	19,65%	20,67%	19,86%	20,56%	20,38%	21,35%	21,06%
Renewables & biofuels	16,22%	18,73%	20,18%	20,71%	26,11%	33,51%	30,59%	30,46%	40,47%	40,92%	35,74%	39,36%	32,90%
Hydro	7,96%	9,97%	10,02%	8,34%	9,91%	15,10%	11,21%	8,12%	14,37%	15,42%	11,18%	14,51%	7,64%
Wind	7,32%	7,79%	9,05%	10,51%	12,95%	14,69%	14,61%	16,64%	19,48%	18,66%	17,57%	17,81%	17,82%
Solid biofuels & renewable wastes	0,70%	0,73%	0,75%	0,85%	1,01%	1,05%	1,30%	1,38%	1,69%	1,62%	1,70%	1,74%	1,86%
Biogases	0,22%	0,20%	0,20%	0,19%	0,18%	0,28%	0,27%	0,29%	0,34%	0,33%	0,35%	0,33%	0,34%
Liquid biofuels	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Solar	0,02%	0,04%	0,17%	0,82%	2,06%	2,38%	3,20%	4,02%	4,58%	4,90%	4,94%	4,97%	5,22%
Geothermal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Tide, Wave & Ocean	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wastes non-RES	0,16%	0,20%	0,24%	0,25%	0,26%	0,22%	0,27%	0,24%	0,24%	0,25%	0,27%	0,27%	0,28%
Other	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Table D - 6: Electricity grid generation mix evolution in previous years in the United Kingdom for each source of energy considered in the Fleet Model.

Market Generation Mix													
by Source Type	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Solid fossil fuels, peat and products, oil shale & oil sands	33,80%	37,47%	34,26%	31,98%	27,35%	28,16%	29,47%	39,24%	36,36%	29,65%	22,39%	9,04%	6,66%
of which hard coal	33,80%	37,47%	34,26%	31,98%	27,35%	28,16%	29,47%	39,24%	36,36%	29,65%	22,39%	9,04%	6,66%
of which brown coal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Oil & petroleum products	1,34%	1,55%	1,27%	1,73%	1,59%	1,26%	0,85%	0,79%	0,58%	0,57%	0,60%	0,56%	0,48%
Natural gas & manufactured gas	38,74%	35,86%	42,17%	45,67%	44,57%	46,27%	40,08%	27,88%	27,15%	30,26%	29,79%	42,48%	40,64%
of which natural gas	38,32%	35,45%	41,78%	45,31%	44,19%	45,97%	39,81%	27,53%	26,75%	29,84%	29,47%	42,25%	40,42%
Nuclear	20,49%	18,99%	15,88%	13,50%	18,34%	16,26%	18,75%	19,35%	19,71%	18,85%	20,76%	21,14%	20,79%
Renewables & biofuels	4,99%	5,53%	5,93%	6,67%	7,68%	7,68%	10,36%	12,15%	15,66%	19,94%	25,41%	25,37%	30,21%
Hydro	1,97%	2,13%	2,25%	2,37%	2,37%	1,76%	2,34%	2,27%	2,12%	2,59%	2,67%	2,46%	2,60%
Wind	0,73%	1,06%	1,33%	1,83%	2,46%	2,69%	4,34%	5,45%	7,93%	9,45%	11,88%	10,98%	14,78%
Solid biofuels & renewable wastes	1,09%	1,11%	1,04%	1,11%	1,37%	1,62%	1,90%	2,28%	3,19%	4,65%	6,49%	6,58%	7,14%
Biogases	1,20%	1,23%	1,31%	1,35%	1,48%	1,59%	1,72%	1,77%	1,86%	2,04%	2,14%	2,28%	2,28%
Liquid biofuels	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Solar	0,00%	0,00%	0,00%	0,00%	0,01%	0,01%	0,07%	0,37%	0,56%	1,20%	2,22%	3,07%	3,41%
Geothermal	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Tide, Wave & Ocean	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Wastes non-RES	0,64%	0,60%	0,48%	0,46%	0,47%	0,37%	0,49%	0,58%	0,55%	0,74%	1,05%	1,42%	1,23%
Other	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

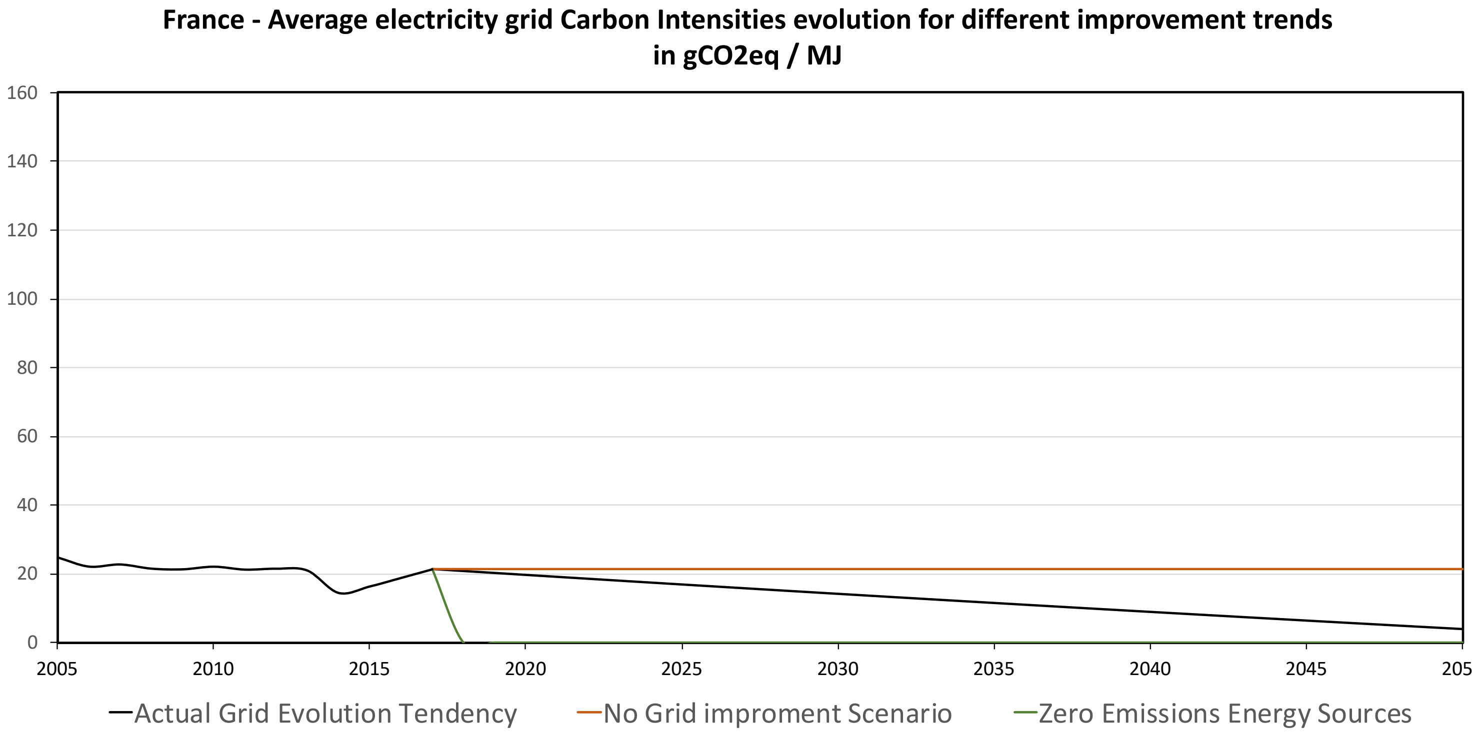

Figure D - 1: Future electricity gird tendencies for France. Average Carbon Intensity evolution in gCO2eq / MJ.

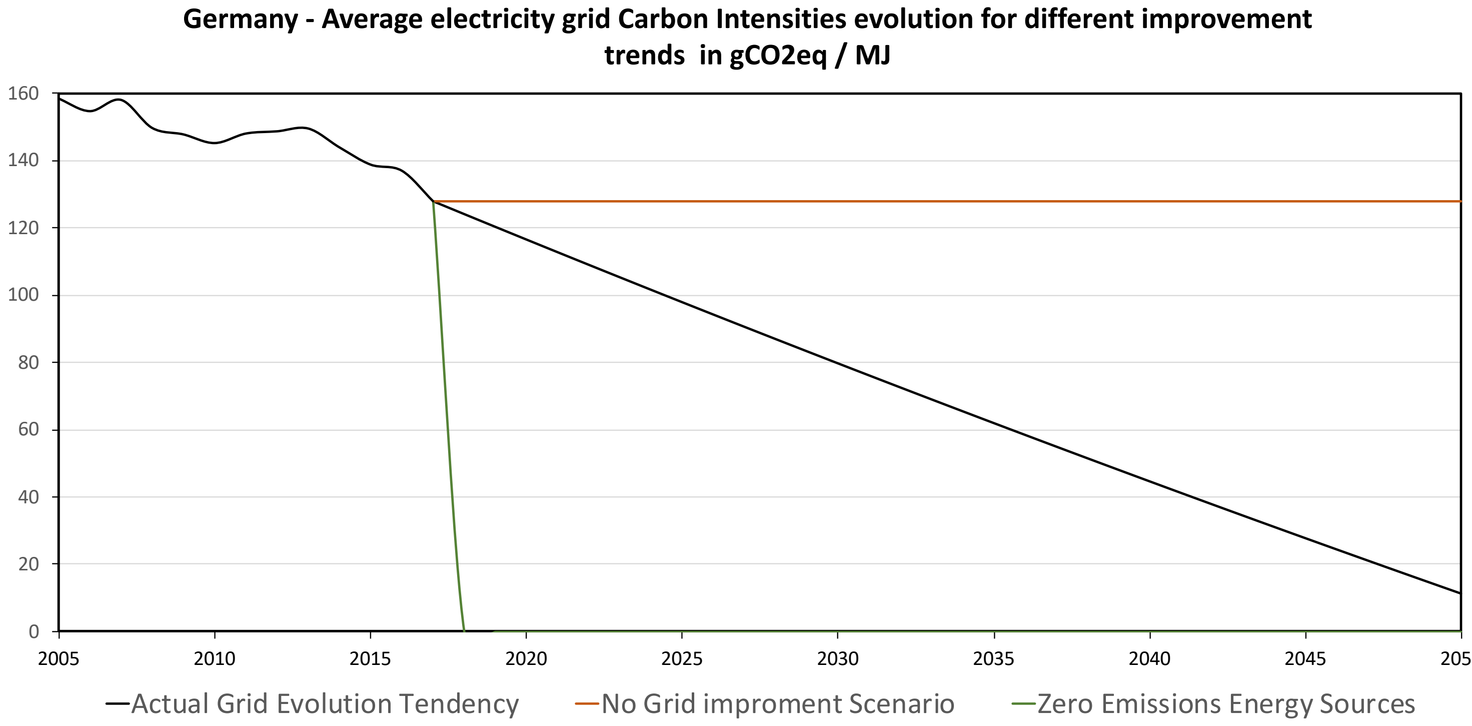

Figure D - 2: Future electricity gird tendencies for Germany. Average Carbon Intensity evolution in gCO2eq / MJ.

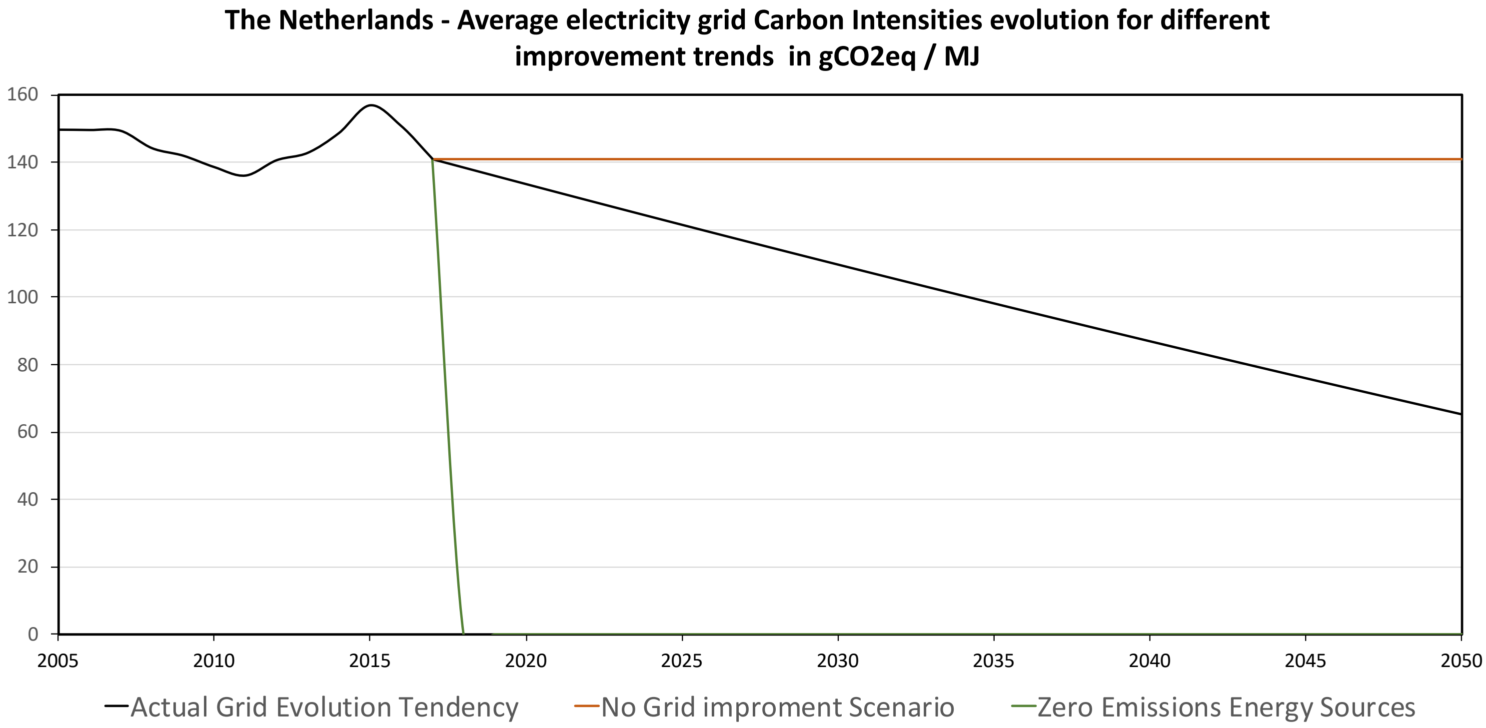

Figure D - 3: Future electricity gird tendencies for the Netherlands. Average Carbon Intensity evolution in gCO2eq / MJ.

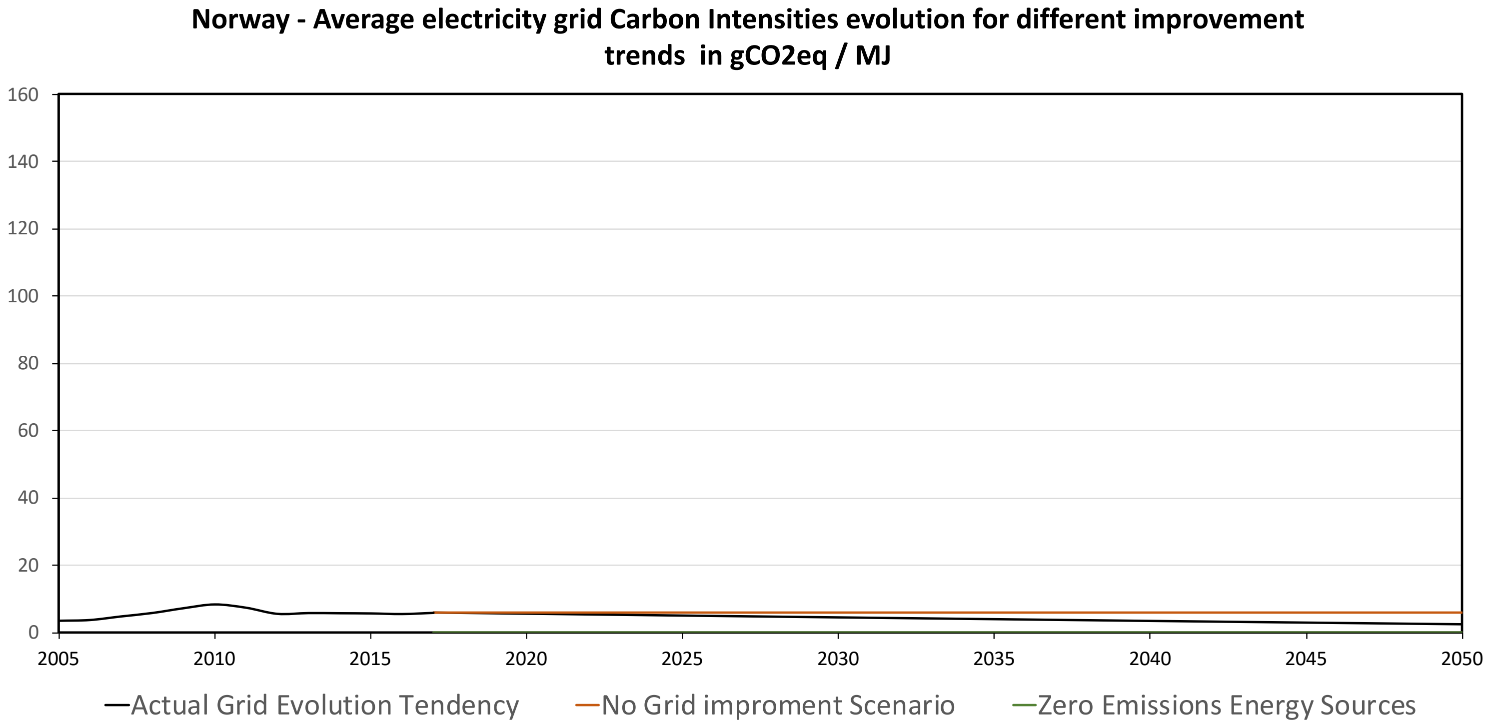

Figure D - 4: Future electricity gird tendencies for Norway. Average Carbon Intensity evolution in gCO2eq / MJ.

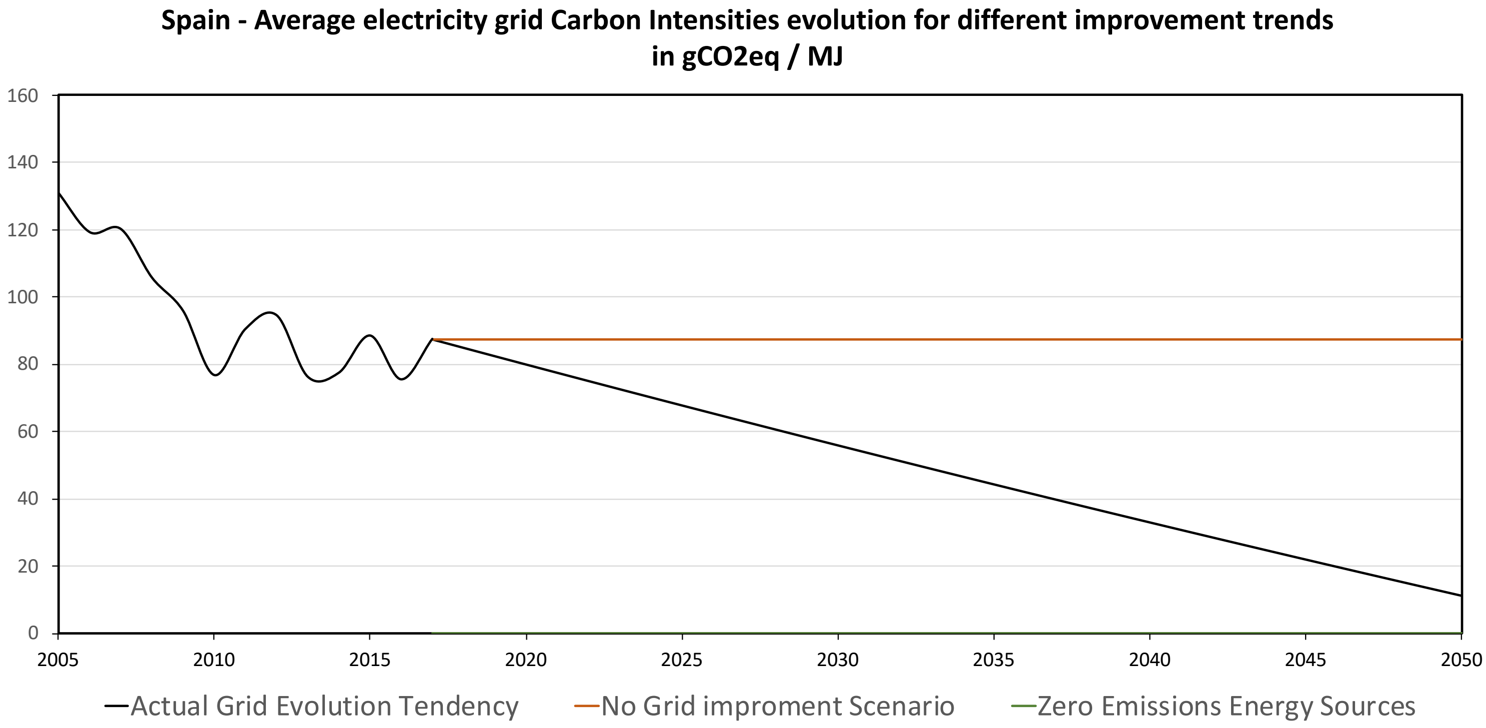

Figure D - 5: Future electricity gird tendencies for Spain. Average Carbon Intensity evolution in gCO2eq / MJ.

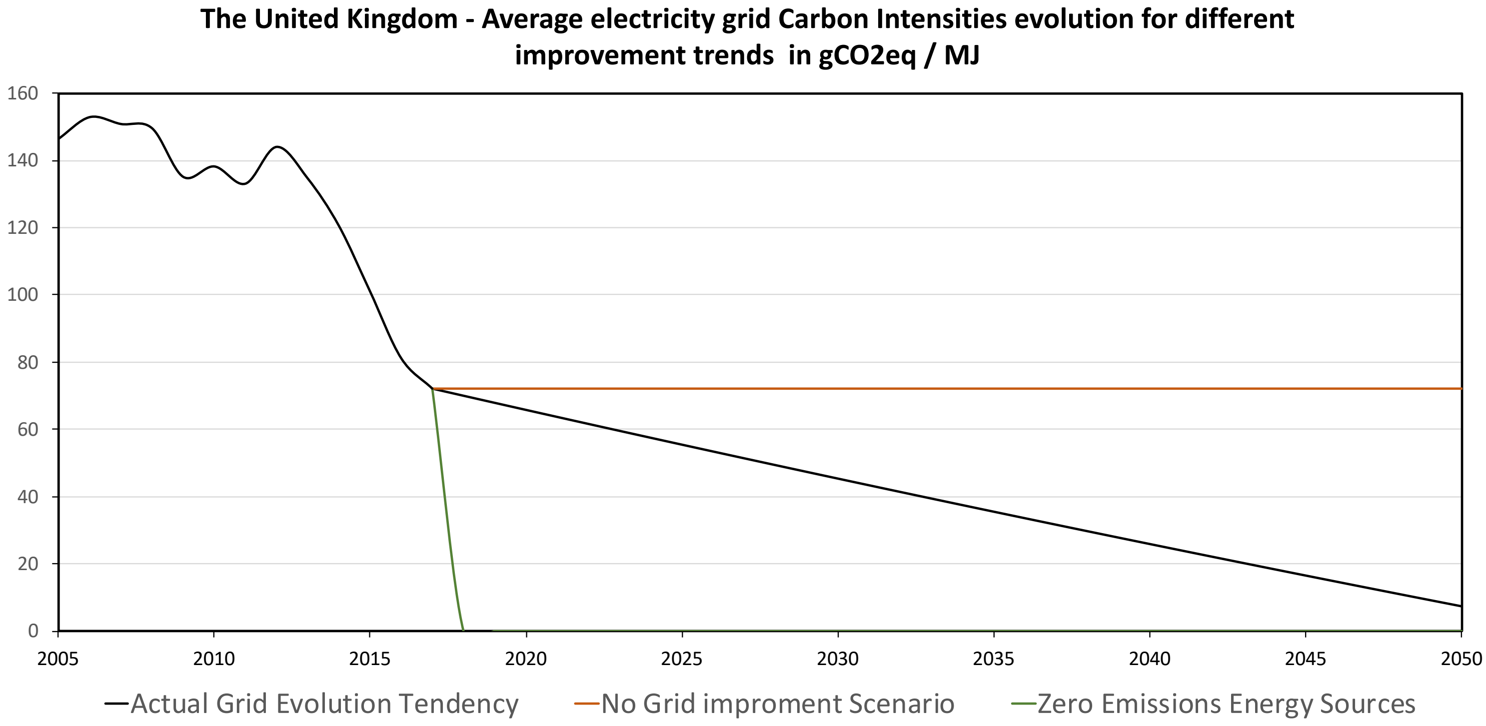

Figure D - 6: Future electricity gird tendencies for the United Kingdom. Average Carbon Intensity evolution in gCO2eq / MJ.