ISCTE Business School
Instituto Universitário de Lisboa

# How do policy incentives influence the adoption of Electric Vehicles?

Elitza Vladimirova Ivanova

Dissertation submitted as partial requirement for the conferral of
Master in International Management

## Supervisor:

Prof. António José Correia Vieira da Silva,

Prof., ISCTE Business School, Management Department

Lisbon, Portugal

September 2018

ISCTE Business School
Instituto Universitário de Lisboa

How do policy incentives influence the ado
Vehicles?

**Elitza Vladimirova Ivanov**

# ABSTRACT

Battery electric vehicles (BEVs) are an effective way to reduce fossil fuel consumption and greenhouse gas emissions. BEVs result in lower energy consumption, greenhouse gas emissions, and urban air pollution compared to internal combustion engine vehicles (ICEVs). Although the uptake of EVs has been significant in a short period of time, most government goals for adoption have not been met and the number of BEVs on the road is still low. Therefore, in order to reduce current greenhouse gas emissions from the transport sector, a vast number of governments have implemented different policy incentives, aiming to stimulate the mass adoption of electric vehicles. The policy makers have introduced two main types of policies – purchase-based and use-based. This work seeks to determine the relationship of those policy incentives to the market deployment of BEVs to mainstream consumers with demographics and vehicle attribute preferences most common to today's new vehicle purchasers. Moreover, this research argues that policies intending to stimulate the uptake of BEVs should not focus on mainstream consumers, but instead they should refocus on niche markets and early adopters, targeting them differently. Regarding to that, this work also presents findings, that that there are two main groups of early adopters – high-end and low-end adopters, which have different socio-economic profile and different opinions of their vehicles with high-end adopters viewing their BEVs more preferentially. BEV policies approaching early adopters and niche markets differently would create complementary system that will lead to increased BEV market penetration and realization of intended societal benefits.

**Keywords**: Battery Electric Vehicle, Adoption, Policy Incentives, Early Adopters, Greenhouse Gas Emissions.

**JEL Classification System**: F23, M16

# ABSTRACT

Os veículos eléctricos a bateria são uma forma eficaz de reduzir o consumo de combustível fóssil e a emissão de gases de efeito de estufa. Os VEB para além de terem como resultado um consumo de energia e emissão de gases significativamente mais reduzidos, têm um impacto menor na poluição atmosférica urbana, em comparação, aos veículos com motor de combustão interna.

Embora a receptividade dos VE tenha aumentado significativamente num curto período de tempo, a maioria dos objetivos governamentais e incentivos à adopção de VE ficaram aquém e consequentemente, o número de VE na estrada é consideravelmente baixo.

Com o objectivo de reduzir a emissão de gases de efeitos de estufa provenientes do sector dos Transportes, um vasto número de entidades governamentais implementou diversas políticas de incentivos com a finalidade de estimular a adopção em massa de VE. Os decisores políticos introduziram dois tipos de medidas: baseadas na compra ou na utilização.

Este trabalho de investigação visa determinar a relação destas políticas de incentivos com o desenvolvimento do mercado de VE para consumidores *mainstream,* com características demográficas e preferências de atributos mais comuns aos novos compradores de veículos. Essencialmente, esta investigação tem como argumento que os focos deveriam ser mercados de nicho e novos consumidores (*early adopters*), ao invés de consumidores *mainstream*.

Esta investigação apresenta, ainda, resultados como a distinção de dois grupos de *early adopters - high-end and low-end adopters* – que têm diferentes perfis socioeconómicos e diferentes preferências quanto à escolha dos veículos. As políticas dedicadas aos veículos eléctricos a bateria dirigidas a mercados de nicho e *early adopters* iriam criar uma forma complementar de impulsionar a penetração de mercado dos veículos eléctricos a bateria e a concretização dos benefícios sociais pretendidos.

**Palavras-chave:** Veículos Eléctricos a Bateria, Adoção, Incentivos politicos, Emissão do efeito estufa.

**JEL Classification System**: F23, M16

# ACKNOWLEDGMENTS

First of all, I would like to express my sincere gratitude to my supervisor, Prof. Antonio Vieira da Silva, for his guidance and recommendations, as well as for all the availability and encouragement throughout all this work. Without him this work would not be possible.

Secondly, I thank my family, in particularly my parents, who have gave me the opportunity to make this work, and who have always expressed their trust, sympathy, inputs and patience towards me.

Lastly, I thank all the others who have somehow listened to my despairs and who made me fought for this achievement.

To all, I am deeply thankful.

# GLOSSARY

AFV – Alternative Fuel Vehicles

BEV – Battery Electric Vehicle

$CO_2$ – Carbon Dioxide

CSO – Car Sharing Organizations

EV – Electric Vehicles

EVSE – Electric Vehicle Supply Equipment

FCEV – Fuel Cell Electric Vehicles

GDP – Gross Domestic Product

GHG – Greenhouse Gas

HEV – Hybrid Electric Vehicle

ICE – Internal Combustion Engine

IPEEC – International Partnership for Energy Efficiency Cooperation

ITC – Integrated Transaction Control System

LDV – Light Duty Vehicles

MBD – Million Barrel per Day

NOK - Norwegian Krone

NOx – Nitrogen Oxides

OEM – Original Equipment Manufacturer

PHEV – Plug-In Electric Vehicle

REEV – Range Extended Electric Vehicles

TWh – Terawatt Hours

# Table of Contents

# 1. Introduction

The society of today is intensively engaged with sustainability and how to reduce local emissions in order to respond adequately to the present environmental changes. One of the first steps taken will be to guarantee climate-friendly mobility. Moreover, electric drive technology exists for more than a century but it was not a viable transport option due to limited range and production costs when compared with the internal combustion engine technology. Only recently, with battery technology development, electric cars come into scene again and many studies have been done in order to evaluate the benefits of transport electrification in terms of energy and emissions reductions.

Therefore, despite the fact that the global and local markets of light duty electric vehicles (EVs) are still at their infancy, the age of the automobile with internal combustion engines may be over. The global crisis caused by our devotion to internal combustion engine vehicles, which belch forth nearly a quarter of the world's CO2 emissions and take about 1.3 million lives each year, has risen convictions that the only exit possible would be the death of the traditional automobile (Seiler 2018).

This thesis focuses on the deployment of light duty electric vehicles (EVs) and moreover, on the policies taken to incentivize the development of the EVs' market. Main purpose behind that incentivization is to keep up with the latest standards invented to diminish the plenty of emissions caused by our daily car usage.

First, an overview of the Global Energy Efficiency will be presented in order for the readers to see what $CO_2$ percentage the transportation sector globally takes and what are the International goals needed to be reached for making the automotive sector more environmental friendly.

Second, a specification of the different types of electric vehicles, which have been introduced onto the global market, will be presented and the benefits of driving daily an electric vehicle will be assessed.

Third, a deeper look into the policies, launched to incentivize the deployment of EVs will be taken, and more specifically, what are the determinants which should be taken into account so that a particular policy stimulus will have a positive impact on potential EV adopters.

Finally, a policy comparison between Norway, as one of the global leaders of automotive electrification, and Portugal, a country which aims to catch up with the global green standards, will be made in order to assess if the policy incentives have a direct impact on the EV deployment uptake. In this regard, the comparison between those two countries will serve as an example as this work does not include conducted interviews due to the initial research stages, which the electric vehicle market shows, and because of the fact that the majority of data gathered is taken from studies that sample members of the general population and not actual adopters of the vehicles.

# 2. Literature Review and Theoretical Background

## 2.1 Literature Review

The study of the policy incentives influence on the electric vehicle adoption posits two main blocks for the literature review. The first one refers to the energy efficiency and the evolution of the transport towards a more sustainable and regulated sector, which incorporates the work of various organizations in this field. The second one focuses on the development of electric vehicles, which are seen as a main opportunity to make the transportation less polluting to the environment.

## 2.2 Energy Efficiency

At its essence, energy efficiency defines as using less energy to provide the same service. Energy efficiency is everywhere, which means that opportunities for improvements can also be found everywhere – from residential buildings to transport to energy-intensive industries.

Its importance goes beyond reduced energy demand and associated cost savings as a matter of fact that energy efficiency can deliver multiple benefits to many different stakeholders and it is one of the most cost-effective ways to reduce carbon emissions in the energy sector (Renewable Energy & Energy Efficiency Partnership 2012).

The challenge behind its effectiveness is that increasing energy efficiency costs money up front, which in many cases will be paid back in the form of reduced energy costs within a short time of period. Despite significant investments in energy efficiency (around 231 billion USD in 2016) a vast majority of economically viable energy efficiency investments remain untapped (Poullikkas 2015).

However, the international policy agenda in recent years shows that things are changing and that energy efficiency has been increasingly prioritised. Governments are becoming more and more aware of the importance of energy efficiency to achieve energy security and overall balance in the energy system – in addition to its cost-effectiveness and multiple benefits. Furthermore, new models show that energy efficiency will be paramount to achieving the GHG emissions reductions that are necessary in the energy sector to attain the goals of the Paris Agreement (United Nations/Framework Convention on Climate Change 2015).

The role of international cooperation is a key means for governments to progress energy efficiency implementation at the national and sub-national levels. It allows countries to share existing good practices, knowledge and technological solutions among peers as well as to collectively work towards energy efficiency standards and goals, where relevant. In doing so, they can accelerate the design and deployment of energy efficiency policies and technologies in a cost-effective way, leading to greater global uptake of energy efficiency and helping it become the “first fuel”.

### 2.3 IPEEC Organization

IPEEC is an autonomous partnership of nations founded in 2009 by the Group of Eight (G8) to promote collaboration on energy efficiency. Its membership now includes 17 of the Group of 20 (G20) economies, which represent over 80% of global energy use and over 80% of global greenhouse gas emissions (Lesage, Van de Graaf, and Westphal 2010).

IPEEC provides information to decision makers in major economies, facilitating candid discussing for exchanging ideas and experiences on energy efficiency. It helps countries undertake joint projects to develop and implement energy efficiency policies and measures on a global scale.

In the previous year, 2017, IPEEC focused on supporting energy efficiency improvement through the activities of its country-led task groups in the following areas: appliances and equipment, buildings, industrial energy management, electricity generation, transport, finance, data and top ten best practices and best available technologies. Nine of IPEEC's task groups progress work under the G20 Energy Efficiency Leading Programme (the Leading Programme) - the G20's first long-term framework for energy efficiency, for which IPEEC serves as the lead coordinating organization in cooperation with other major international organizations (International Energy Agency 2017a).

Figure 1. (IPEEC 2017) illustrates what percentage of global oil each of the different sectors consumes. It is evident that the transportation consumes more than the half of the global oil, which is an argument about how crucial the efficiency of this sector is.

As this work focuses on the policies taken in order to make the automotive sector more sustainable, a deeper look into the statistics of the transport sector will be taken with the purpose to show that constant improvements are needed for reducing the carbon emissions of the light-duty vehicles.

## 2.4 Transport Sector

The world has over 1.5 billion motor vehicles today with future projections that that number will surpass 2 billion by 2020. The transport sector consumes about 48 million barrels of oil per day (MBD), against current global oil consumption of 93 MBD (Administration 2018). More than half of global oil production goes to fuel the transport sector (Figure 1), which

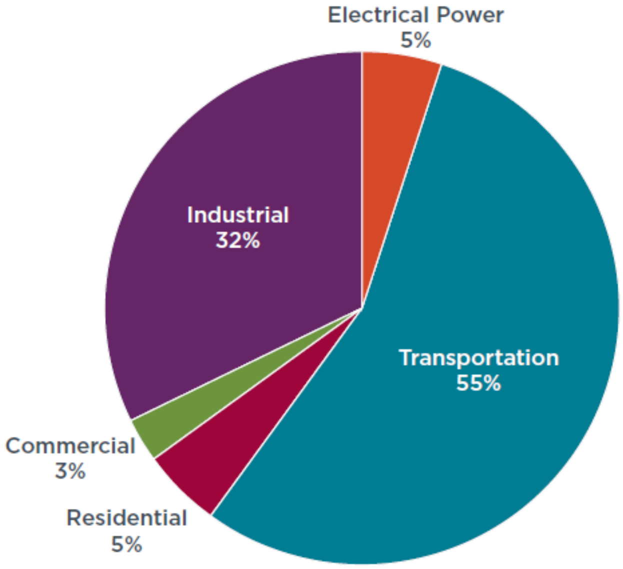


**Figure 1.** Global oil consumption by sector in 2010$^4$

is almost entirely powered by oil. As a result the transport related greenhouse gas (GHG) emissions have significantly grown over the past years and account for more than quarter of today’s global greenhouse gas emissions. Moreover, Fulton, 2009, expects that without significant technological innovation or policy intervention this development will continue and transport related GHG emissions will double by 2050. Road transport is the biggest contributor to these GHG emissions and their potential future growth (Fulton, Cazzola, and Cuenot 2009; Meyer, Leimbach, and Jaeger 2007).

In 2010, almost a quarter of all anthropogenic $CO_2$ emissions, 8.8 gigatons (Gt), came from the global transport sector (Figure 2). Within the transport sector, on-road vehicles accounted for about three-quarters of fuel consumption (35 MBD) and $CO_2$ emissions (6.5 Gt) (IPEEC 2017).

Currently, the transport sector accounts for around 23% of total global energy use, and it is estimated that this may more than double by 2040 as a result of projected increases in the number of light-duty vehicles and associated fuel consumption (Renewable Energy & Energy Efficiency Partnership 2012). Besides the fact that the transport sector plays a vital part in world economic growth in moving people and goods throughout the world, it also has a significant and growing environmental footprint. The transport sector consumes more than half of global oil production, and releases nearly a quarter of all anthropogenic carbon dioxide emissions. Motor vehicles and engines, especially those fueled with diesel, contribute to ambient air pollution responsible for millions of premature deaths worldwide each year.

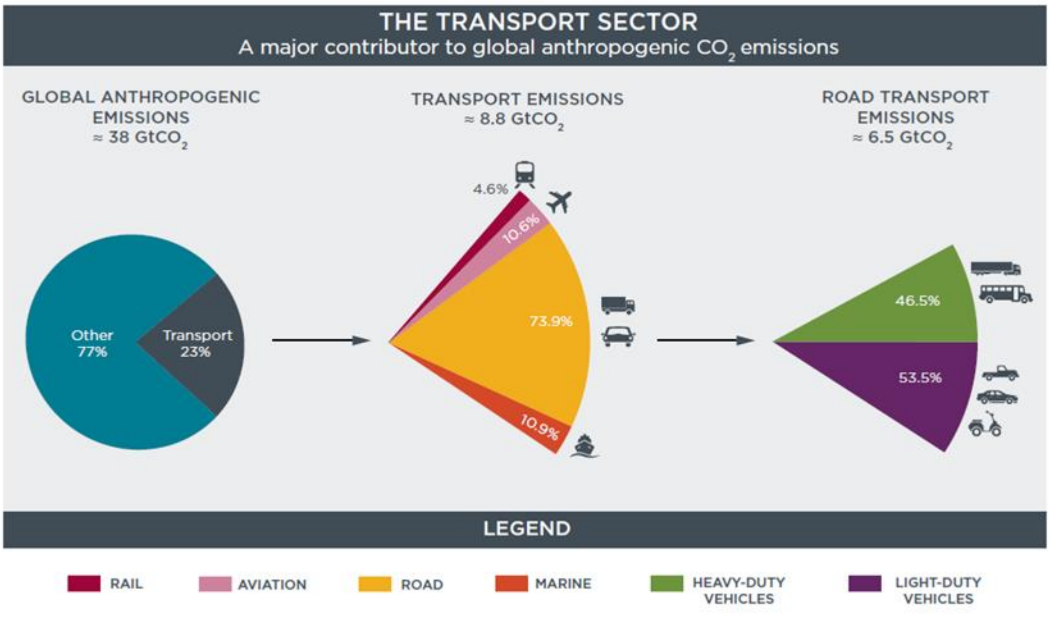


**Figure 2.** Global anthropogenic $CO_2$ emissions from the transport sector[9]

Moreover, assessing the motor vehicle energy efficiency and emissions control programs of the IPEEC' country members shows that substantial societal benefits have accrued to those G20 nations that have adopted clean fuel and vehicle policies identified in this policy brief. For a complementary package of tailpipe emission and fuel quality standards, public health benefits consistently and substantially exceed societal costs, indicating that such policies are cost-effective. Similarly, a significant body of evidence demonstrates that vehicle fuel economy and $CO_2$ standards achieve major reductions in carbon emissions and oil use while simultaneously providing fuel savings and financial benefits to consumers. This indicates a number of policy opportunities for G20 countries. To facilitate future collaboration, three grouping of G20 countries according to current policy status and recommended future actions are proposed in the Table ES-1 (IPEEC 2017).

Later on in this paper the policies of two countries – Norway and Portugal taken to incentivise the deployment of electrical vehicles, will be compared. According to this classification Portugal as a member of the European Union is included in Group 1, which among the rest of the groups shows constant working on its world-class emission standards. Norway as a country, located in Europe, but neither member of the EU nor a member of the G20 countries, is in spite of that one of the major economies working progressively on the launching of more incentives to expand its electric vehicle market.

Overall, G20 countries possess an immense opportunity to help bring forth a fleet of higher-efficiency, lower-emission vehicles. In 2014, G20 countries accounted for over 90% of global vehicle sales. The policies adopted by G20 members thus largely dictate the air pollution, fuel consumption, and $CO_2$ emissions of the global transport sector. Furthermore, a collective

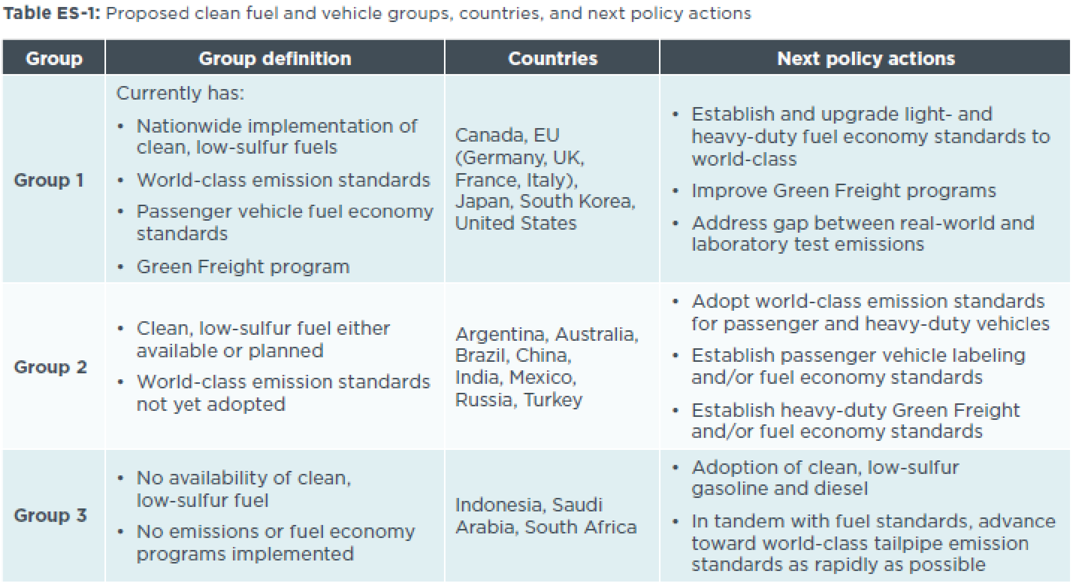


**Table ES-1:** Proposed clean fuel and vehicle groups, countries, and next policy actions

| Group | Group definition | Countries | Next policy actions |
|---|---|---|---|
| **Group 1** | Currently has:<br>• Nationwide implementation of clean, low-sulfur fuels<br>• World-class emission standards<br>• Passenger vehicle fuel economy standards<br>• Green Freight program | Canada, EU (Germany, UK, France, Italy), Japan, South Korea, United States | • Establish and upgrade light- and heavy-duty fuel economy standards to world-class<br>• Improve Green Freight programs<br>• Address gap between real-world and laboratory test emissions |
| **Group 2** | • Clean, low-sulfur fuel either available or planned<br>• World-class emission standards not yet adopted | Argentina, Australia, Brazil, China, India, Mexico, Russia, Turkey | • Adopt world-class emission standards for passenger and heavy-duty vehicles<br>• Establish passenger vehicle labeling and/or fuel economy standards<br>• Establish heavy-duty Green Freight and/or fuel economy standards |
| **Group 3** | • No availability of clean, low-sulfur fuel<br>• No emissions or fuel economy programs implemented | Indonesia, Saudi Arabia, South Africa | • Adoption of clean, low-sulfur gasoline and diesel<br>• In tandem with fuel standards, advance toward world-class tailpipe emission standards as rapidly as possible |

G20 commitment would amplify the impact of these policies and promote sharing of best practices and technology developments among regions. Technical assistance among G20 countries for policy and program design, development, and implementation would accelerate cost-effective policy actions. The publication of the G20 Energy Efficiency Action Plan, held in Brisbane, Australia in 2014, is an important outcome of the G20 summit. Increased collaboration on energy efficiency has significant importance as G20 countries consume 80% of the world's energy output. A mutual work can help spur economic growth, enhance energy security, and improve the environment all over the world. Furthermore, international business efficiencies can be improved through the alignment of energy efficiency approaches and standards (Thiel, Perujo, and Mercier 2010b).

The Energy Efficiency Action Plan identified six focus areas for collaborative activity, including motor vehicles, which is characterized as a new area where the G20 could add value by addressing an emerging challenge or a gap in existing international collaboration. With regard to motor vehicles, the stated objective is to improve energy efficiency and emissions performance.

Globally, major economies regulate their vehicle markets with some type of vehicle tailpipe emissions and/or fuel economy standards. However, many of the various national and regional standards lag best practice in terms of stringency, compliance and enforcement. Accordingly, there is great potential in many countries and regions to adopt world-class standards that would drive investment in clean vehicles and fuels and more fully deploy proven, cost-effective technologies and solutions (Gnann and Plötz 2015).

Therefore, most countries around the globe have chosen to adopt European tailpipe emissions standards as fastest regarding development (IPEEC 2017). Figure 3 (IPEEC 2017) illustrates the progressive reductions in particulate matter emissions by the Euro standards for light-duty vehicles (LDV) and heavy-duty trucks. The European standards are designated by Arabic numerals for light-duty vehicles and Roman numerals for heavy-duty vehicles, and have progressed from Euro 1/I (1992) through Euro 6/ VI (2015). Today, the most advanced European emission control standards are called Euro 6 for light-duty vehicles, and Euro VI for HDV. Additionally, from the Figure 3 could be seen the dramatic effect that each successive Euro vehicle emissions standards has had on particulate matter.

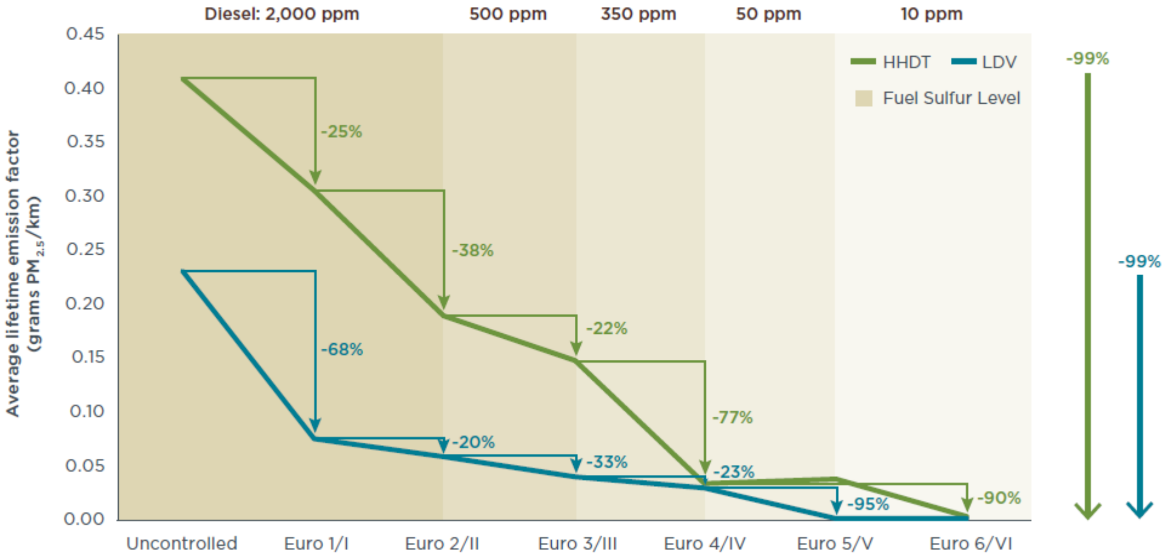


**Figure 3.** European tailpipe emission standards and matching fuel sulfur content[16]

In the recent years, Japan and Europe are home to the world's most efficient fleets of new passenger vehicles, and Europe's 95 g $CO_2$ /km is designated the world-class emission standard. Even though, it is interesting that about three-quarters of global light-duty vehicle sales occur in markets regulated by efficiency standards that drive down $CO_2$ emissions through 2015 (ICCT 2018). These standards only apply to new motor vehicles, and do not require any changes to the existing vehicle fleet. Figure 4 (ICCT 2018) compares all new passenger vehicle fuel economy standards that have been adopted or proposed worldwide, showing their historical progression and future performance targets. Vehicle efficiency

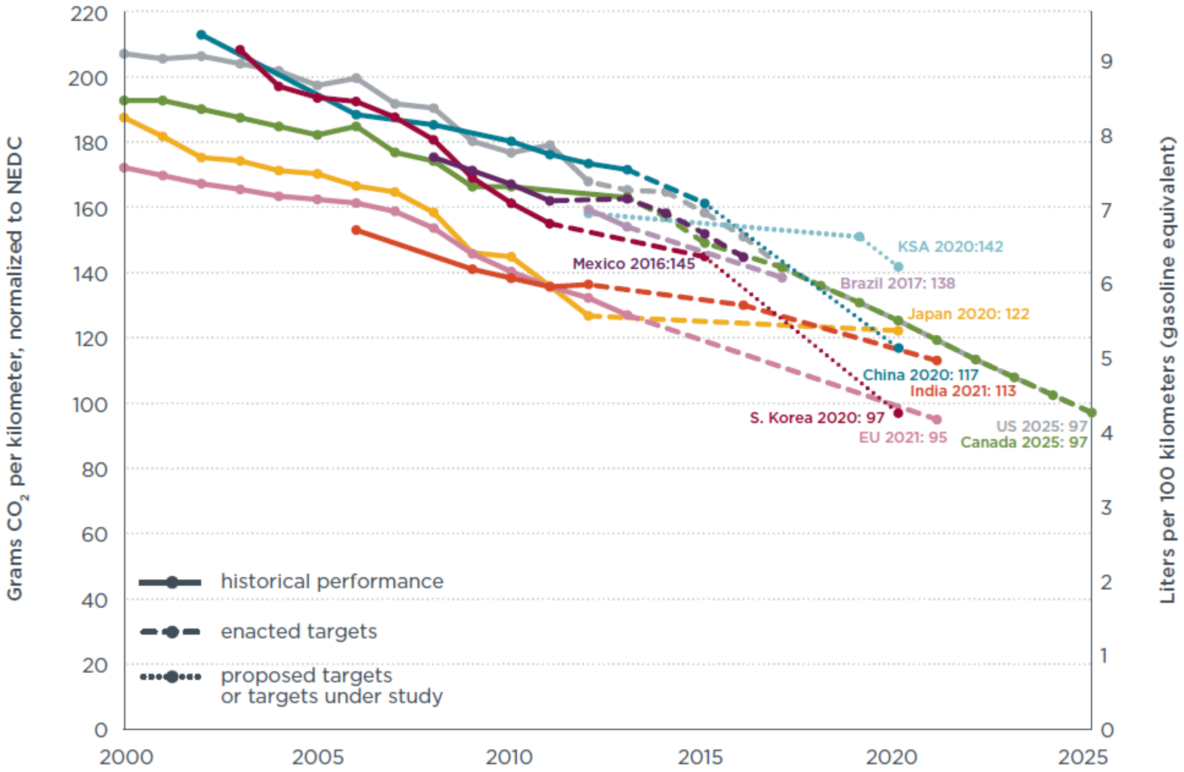
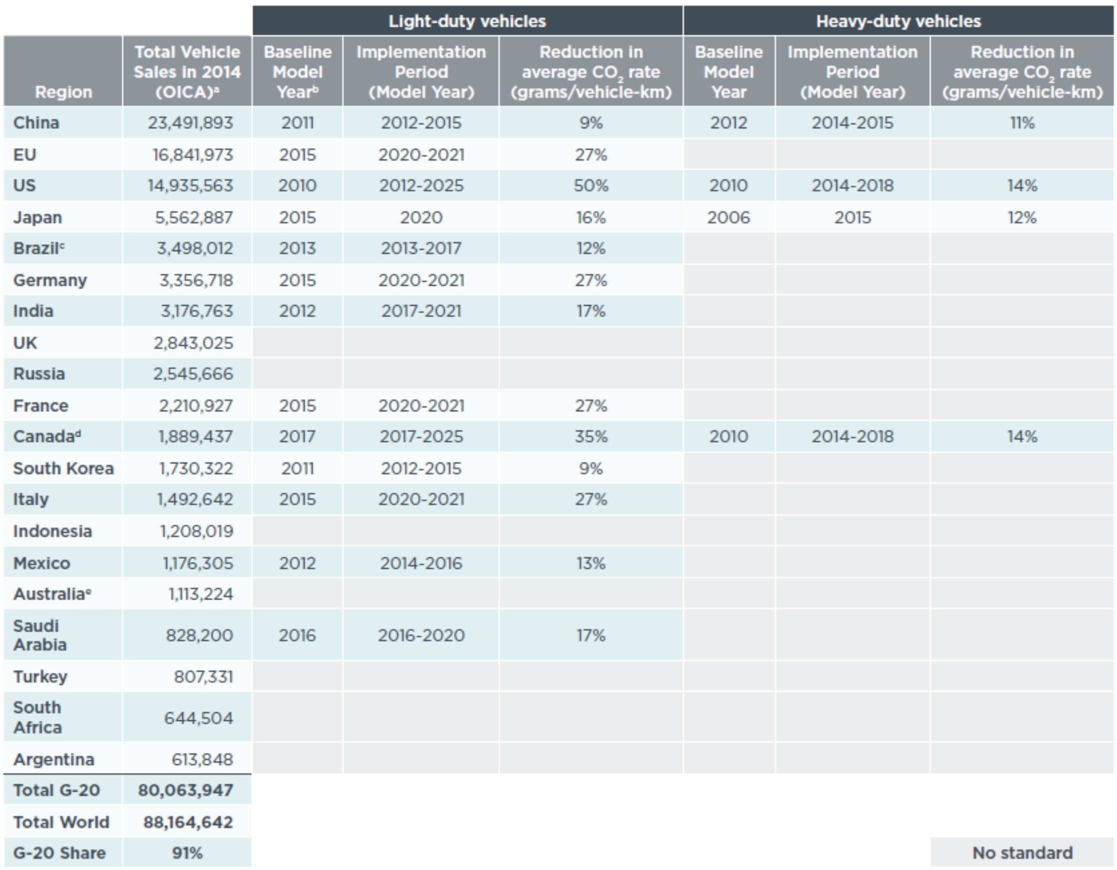


**Figure 4.** Comparison of light-duty vehicle efficiency standards (passenger cars only, light-duty trucks excluded) requirements are shown in terms of both $CO_2$ emissions (left axis) and fuel consumption (right axis).

These regulations take different approaches, using various drive cycles and vehicle certification test procedures. Light-duty vehicle regulations typically result in fuel savings that greatly exceed the costs of efficiency-improving technologies. New electrified vehicle concepts have already entered the market in Europe. The expected gains in environmental performance for these new vehicle types are associated with higher technology costs. In parallel, the fuel efficiency of internal combustion engine vehicles and hybrids is continuously improving, which in turn advances their environmental performance but also leads to additional technology costs versus today's vehicles (Thiel, Perujo, and Mercier 2010a). Additionally, most of the analyses done so far claim large environmental benefits associated to electric driving versus driving with combustion engines.

**Table 4.** Comparison of light-duty and heavy-duty vehicle fuel efficiency regulations of G20 countries*



| | | Light-duty vehicles | | | Heavy-duty vehicles | | |
|---|---|---|---|---|---|---|---|
| Region | Total Vehicle Sales in 2014 (OICA)[a] | Baseline Model Year[b] | Implementation Period (Model Year) | Reduction in average $CO_2$ rate (grams/vehicle-km) | Baseline Model Year | Implementation Period (Model Year) | Reduction in average $CO_2$ rate (grams/vehicle-km) |
| China | 23,491,893 | 2011 | 2012-2015 | 9% | 2012 | 2014-2015 | 11% |
| EU | 16,841,973 | 2015 | 2020-2021 | 27% | | | |
| US | 14,935,563 | 2010 | 2012-2025 | 50% | 2010 | 2014-2018 | 14% |
| Japan | 5,562,887 | 2015 | 2020 | 16% | 2006 | 2015 | 12% |
| Brazil[c] | 3,498,012 | 2013 | 2013-2017 | 12% | | | |
| Germany | 3,356,718 | 2015 | 2020-2021 | 27% | | | |
| India | 3,176,763 | 2012 | 2017-2021 | 17% | | | |
| UK | 2,843,025 | | | | | | |
| Russia | 2,545,666 | | | | | | |
| France | 2,210,927 | 2015 | 2020-2021 | 27% | | | |
| Canada[d] | 1,889,437 | 2017 | 2017-2025 | 35% | 2010 | 2014-2018 | 14% |
| South Korea | 1,730,322 | 2011 | 2012-2015 | 9% | | | |
| Italy | 1,492,642 | 2015 | 2020-2021 | 27% | | | |
| Indonesia | 1,208,019 | | | | | | |
| Mexico | 1,176,305 | 2012 | 2014-2016 | 13% | | | |
| Australia[e] | 1,113,224 | | | | | | |
| Saudi Arabia | 828,200 | 2016 | 2016-2020 | 17% | | | |
| Turkey | 807,331 | | | | | | |
| South Africa | 644,504 | | | | | | |
| Argentina | 613,848 | | | | | | |
| **Total G-20** | **80,063,947** | | | | | | |
| **Total World** | **88,164,642** | | | | | | |
| **G-20 Share** | **91%** | | | | | | |

No standard

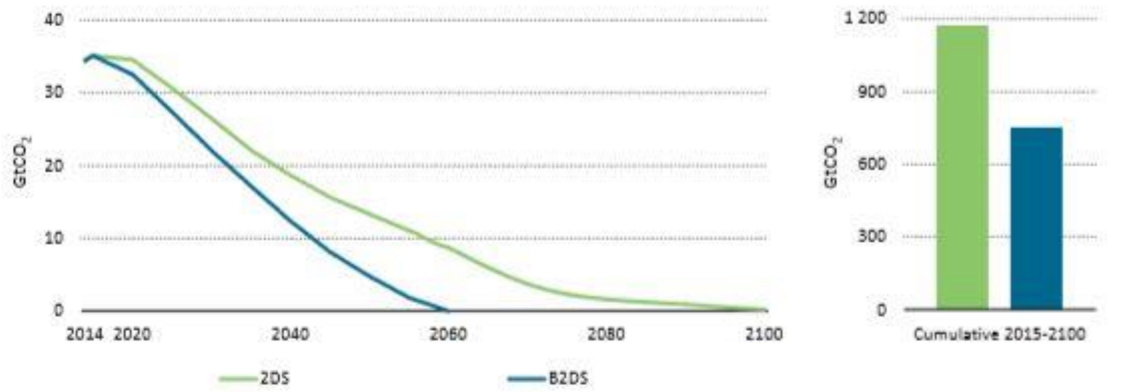
Overall, Table 4 (IPEEC 2017) shows that a large fraction of the G20 countries are already achieving world-class standards for vehicles and fuels. Specifically, the European Union and its member states, Canada, Japan, South Korea and the USA have all adopted world-class standards. The EU member states that are also individual G20 members - Germany, the United Kingdom, France, and Italy - are individually listed in the table, but it is important to note that the European Commission sets European-wide vehicle and fuel standards that these countries and other European Union member states are obliged to follow. As an example, the achievement of the targets as outlined in the European Renewables Directive (Directive 2009/28/EC) was taken as a basis for calculating the 2020 $CO_2$ intensity of electricity generation and for the renewable content of the road fuels. For the $CO_2$ intensity of the future electricity mix, the policy measures of 20% GHG emission reduction in 2020 compared to 1990 levels in the EU and further energy efficiency improvements as outlined in the New Energy Policy scenario in DG TREN (2008) were additionally applied to the renewables target (Directive 2009/28/EC).

However, the Paris Agreement announces in December 2015 its objective of limiting the increase in the global average temperature to well below 2°C above preindustrial levels and that efforts towards limiting the temperature increase to 1.5°C above preindustrial levels will be pursued (United Nations 2015). The Figure below depicts the GHG emissions reductions that could be compatible with this target by looking at two carbon budgets that reflect two possible IEA scenarios (U.S. Energy Information Administration 2017):

- 1170 $GtCO_2$ of cumulative emissions for the 2015-2100 period, as in the IEA Two Degree Scenario (2DS), providing a 50% chance of limiting average future temperature increases to 2°C
- 750 Gt $CO_2$ of cumulative emissions for the 2015-2100 period, as in the Beyond Two Degree Scenario (B2DS), coupled with a 50% chance of limiting average future temperatures increases to 1.75°C.

In both cases represented in the following Figure 3 (U.S. Energy Information Administration 2017), energy-related GHG emissions need to reach net-zero in the second half of this century: close to 2060 for the B2DS and close to 2090 for the 2DS. The transport sector, accounting for more than 23% of global energy-related GHG emissions, needs to deliver major emissions cuts for countries to achieve their goals.

**Figure 3 • GHG emission budgets and emission trajectories to 2100 for the energy sector, 2DS and B2DS**



Source: IEA (2017b).

**Key point:** Without net negative emissions, energy sector $CO_2$ emissions need to fall to zero in the second half of the century to meet the ambition of the Paris Agreement.

In all IEA scenarios a large role plays the electrification of transport aiming to achieve the decarbonization of the energy system, where increasing transport electrification goes along with decarbonizing the electricity sector (U.S. Energy Information Administration 2017). Undoubtedly, the electrification of the transport sector plays crucial role for the IEA targets.

Therefore, with zero tailpipe emissions in the case of full-electric driving vehicles, EVs also offer a clean alternative to vehicles with ICEs by helping to reduce exposure to air pollution resulting from fuel combustion and limiting noise. The importance of EVs for the reduction of air pollution and noise is well demonstrated by the leading role that cities assume in promoting EV deployment: in 2015, nearly a third of global electric car sales takes place in just 14 cities (Hall, Moultak, and Lutsey 2017). Major global urban centers also tend to witness higher electric car market penetration compared to their country averages.

## 2.5 Electric Vehicles

There is a general perception of the EVs as an environmentally benign technology. Electric vehicles couple with low-carbon electricity sources and offer potential for reducing greenhouse gas emissions and exposure to tailpipe emissions from personal transportation. In considering these benefits, it is important first to get a better understanding about the electric vehicles itself and to distinguish the different types of the electric two-wheelers.

### 2.5.1 Types of Vehicles

Vehicle manufacturers presently use five main types of electric vehicle technology. These technologies vary in the way the on-board electricity is generated and/or recharged, and in the way the internal electric motor and combustion engine are coupled. The mix of battery capacities, charging capabilities and technological complexity provides consumers with a choice of options when it comes to vehicle ranges, refueling options and price (Kley, Lerch, and Dallinger 2011).

- Conventional Vehicles

Conventional vehicles use fossil fuels (petrol or diesel) to power an internal combustion engine. While driving, they produce noise and exhaust emissions that pollute air. Conventional vehicles are inefficient, only about 18 to 25% of the energy available from the fuel is used to move it on the road. Such vehicles have been mass-produced for over a century, and a substantial support infrastructure comprising vehicle manufacturing, repair and refueling facilities has accordingly been developed (Hawkins et al. 2013).

- Battery Electric Vehicles (BEVs)

BEVs are powered solely by an electric motor, using electricity stored in an on-board battery. The battery must be regularly charged, typically by plugging in the vehicle to a charging point connected to the local electricity grid. BEVs have the highest energy efficiency of all vehicle propulsion systems, typically able to convert around 80% or more of the energy stored in the battery into motion. The electric motor is particularly efficient, and regenerative braking provides further efficiency gains. Regenerative braking systems help keep the battery in an electric vehicle charged, by converting into electricity much of the energy that would normally be lost at heat through traditional braking.

There are no exhaust emissions while driving a battery electric vehicle. This helps to improve local air quality. The greatest benefits for the environment occur when BEVs are powered by electricity from renewable sources. However, there are fewer emissions even when electricity comes from the average mix of renewables and fossil fuels used presently in Europe (Berggren and Magnusson 2012). For instance, in the EU-28, in 2014, almost 30% of electricity is produced from renewables.

BEVs, however, still have somewhat limited driving ranges compared to conventional vehicles and typically need a long time to recharge the on-board batteries. BEVs tend to have large batteries to maximise the energy storage capacity and hence allow longer driving ranges. These large batteries generally cost more than those used in hybrids. However, battery costs per kilowatt-hour (kWh) tend to be less expensive for BEVs (Newbery and Strbac 2016).

- Hybrid Electric Vehicles (HEVs)

HEVs have been commercially available for more than 15 years. They combine an internal combustion engine and an electric motor that assists the conventional engine during, for example, vehicle acceleration. The battery of an HEV cannot be charged from the grid but is typically regenerative braking or while the vehicle is coasting.

As an HEV is predominantly powered by its conventional engine, hybridisation can be regarded as a technology added to conventional vehicles with the aim of increasing fuel efficiency, reducing pollutant and $CO_2$ emissions, rather than being an entirely separate type of vehicle. HEV typically have lower fuel consumption and exhaust emissions than conventional technologies. The more sophisticated the hybrid system, the greater the potential to lower emissions. Many different types and models of HEVs exist, ranging from “micro-HEVs”, whose only fuel-saving feature is regenerative braking and where the electric engine on its own is not capable of powering the vehicle, through to “full HEVs”, which are able to drive small distances in electric-only mode (Al-Alawi and Bradley 2013).

The ways in which the conventional engine and electric motor are joined can also differ across different HEV models. Parallel hybrids employ an electric motor and a combustion engine that are connected so they power the vehicle together. Series-parallel hybrids, or power-split hybrids, combine power from conventional and electric motors to drive the wheels but, unlike a parallel hybrid, these vehicles can be driven from the battery alone, although typically only at low speeds for short distances. Their configuration can allow the vehicle to be powered 100% from the conventional engine, 100 % from the electric motor or in any intermediate ratio, e.g. 30% electric motor and 70% combustion engine.

Batteries for hybrids, both plug-in and non-plug-in, tend to be more expensive than the ones for battery electric vehicles in terms of price per kWh. This higher price is mainly because hybrid vehicles require greater power-to-energy performance (Al-Alawi and Bradley 2013).

- Plug-In Hybrid Electric Vehicles (PHEVs)

PHEVs are powered by an electric motor and an internal combustion engine designed to work either together or separately. The on-board battery can be charged from the grid, and the combustion engine supports the electric motor when higher operating power is required or when the battery’s state of charge is low (Zhou, Levin, and Plotkin 2016).

The electric driving range is smaller than for BEVs, as the batteries tend to have smaller capacities. The batteries can have less energy storage capacity because they rely less on electrical power alone to power the vehicle. As an example, the battery capacity in PHEVs is designed more for short trips in the city or commuting, than for long-distance journeys. However, as for REEVs, the combustion engine allows a much longer overall driving range.

Batteries for PHEVs tend to be more expensive than for BEVs in terms of price per kWh. This higher price is mainly because PHEVs require greater power-to energy performance. The environmental impact of PHEVs depends on their operation mode. Running in all-electric mode results in zero exhaust emissions, but relying only on the conventional engine can lead to fuel consumption and emission levels equal or higher than those of conventional vehicles of similar size, because the additional battery increase the vehicle mass. Moreover, as for BEVs, the overall environmental performance of PHEVs depends greatly on the share of renewables in the electricity generation mix. PHEVs can be financially attractive for drivers if the electricity used is cheaper than the petrol or diesel that would have otherwise been used (Zhou, Levin, and Plotkin 2016).

- Range-extended electric vehicles (REEVs)

REEVs have a serial hybrid configuration in which their internal combustion engine has no direct link to the wheels. Instead the combustion engine acts as an electricity generator and is used to power the electric motor or recharge the battery when it is low. The on-board battery can also be charged from the grid. The electric motor is therefore solely responsible for directly powering the vehicle. On advantage of REEVs is that the conventional engine can be small, as it is needed only when the vehicle exceeds its electric driving range. This helps reduce the vehicle's weight. As for a PHEV, an REEV overcomes the problem of a restricted driving range associated with BEVs because it can be fuelled at conventional filling stations (Min, Ye, and Yu 2013).

- Fuel Cell Electric Vehicles (FCEVs)

FCEVs are also entirely propelled by electricity. In this case, the electrical energy is not stored in a large battery system, but is instead provided by a fuel cell 'stack' that uses hydrogen from an on-board tank combined with oxygen from the air. The main advantages of FCEVs over BEVs are their longer driving ranges and faster refuelling, similar to those of a conventional vehicle. Because of the current size and weight of fuel cell stacks, FCEVs are better suited for medium-sized to large vehicles and longer distances. Fuel cell stack technology is in an earlier stage of development than the technologies described above and few models of FCEVs are currently commercially available. Further technological development is needed for FCEVs to improve their durability, lower the costs and establish a hydrogen fuelling infrastructure, including standalone stations or pumps for hydrogen (Vehicle and Explained 2003).

### 2.5.2 Electric Vehicles Charging

As the driving range of many electric vehicles is limited, the type of technology used to charge them, and the time it takes, are very important to consumers. There is even a definition explaining that fear of being stranded with a dead battery miles from a plug, called range anxiety (Bonges and Lusk 2016). However, only battery and fuel cell electric vehicles are totally reliant on charging infrastructure. As the hybrid vehicles also contain a conventional internal combustion engine, it is not critical for them.

In general, there are three basic ways to charge an electric vehicle: plug-in charging, battery swapping or wireless charging.

- Plug-In Charging

In Europe plug-in charging is used by the vast majority of current BEVs and PHEVs. Vehicles are physically connected to a charging point using a cable and a plug. Plug-in charging can occur wherever charging stations are located: at homes, in public streets or on commercial or private premises. Electric vehicles can be charged using normal household domestic sockets, although it is a slow process because normal domestic sockets provide only a low amount of electric current. It can therefore take about eight hours for a typical charge. However, this can be quite suitable for overnight charging. Faster plug-in charging requires specialised infrastructure. Today, most public plug-in stations established at a city, regional or national level offer only normal-speed charging (EC 2013).

There are four different ways in which battery electric vehicles of PHEVs can be charged via plug-in charging. Each of them can involve different combinations of power level supplied by the charging station (expressed in kW), types of electric current used (alternating AC) or direct (DC) current), and plug types. The power level of the charging source depends on both the voltage and the maximum current of the power supply. This determines how quickly a battery can be charged. The power level of charging ranges widely, from 3.3 kW to 120 kW. Lower power levels are typical of residential charging points.

- Mode 1 (slow charging) allows vehicle charging using common household sockets and cables. It is commonly found in domestic or office buildings. The typical charging power level is 2.3 kW. Household sockets provide AC current.

- Mode 2 (slow or semi-fast charging) also uses a non-dedicated socket, but with a special charging cable provided by the car manufacturer. A protection device that is built into the cable offers protection to the electrical installations. It provides AC current.

- Mode 3 (slow, semi-fast or fast charging) uses a special plug socket and a dedicated circuit to allow charging at higher power levels. The charging can be either via a box fitted to the wall (wall box), commonly used at residential locations, or at a stand-alone pole, often seen in public locations. It uses dedicated charging equipment to ensure safe operation, and provides AC current.

- Mode 4 (fast charging) delivers direct current (DC) to the vehicle.

Big disadvantage of high-power, fast charging is that the stronger current is lost during transfer, which means that the efficiency is lower. Furthermore, fast charging can decrease battery lifetime as it reduces the number of total charging cycles. Fast DC charging points are also around three times as expensive to install as a simple AC charger, which is a main reason why so many users are reluctant to invest in the additional costs. While some new electric vehicle models are provided with a DC charging facility, others require the purchase of an additional charging device (Genovese, Ortenzi, and Villante 2015).

- Wireless Charging

Instead of a fixed physical connection between the charging facility and the vehicle, the wireless charging system creates localised electromagnetic field around a charging pad, which is activated when an electric vehicle with a corresponding pad is positioned above it. The wireless method currently operates at only a selected few pilot locations and is yet to be used commercially.

- Battery Swapping

Battery swapping involves replacing a used battery with a fully charged one at a particular swapping station. This offers a rapid way of quickly recharging a vehicle. At present, no major providers in Europe offer battery swapping. A number of barriers have prevented battery-swapping technology from becoming widespread, including the lack of electric vehicle models that support the system, no standard type or size of battery, and the high cost of developing the associated charging and swapping infrastructure.

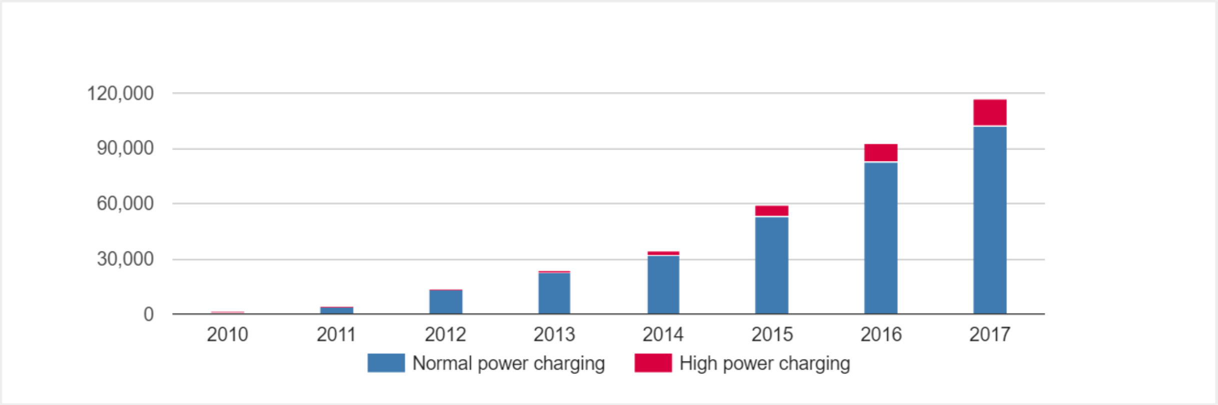
The power level of the charging source depends on both the voltage and the maximum current of the power supply. This determines how quickly a battery can be charged. The power level of charging points ranges widely, from 3.3 kW to 120 kW. Lower power levels are typical of residential charging points.

Behind all the technical specifications, it is obvious that the battery industry has world-changing ambitions. Until recently, it was a transition that many found unthinkable. The internal combustion engine has been the main way of powering vehicles on land and at sea for most of the past century. Huge expansion for lithium batteries for electric vehicles is under way (Economist 2017). The top five manufacturers – Japan’s Panasonic, South Korea’s LG Chem and Samsung SDI, and China’s BYD and CATL – are ramping up capital expenditure with a view to almost tripling capacity by 2020. The vast $5bn gigafactory Tesla is building with Panasonic in Nevada is thought to already be producing about 4GWh a year. Tesla says it will produce 35GWh this year. Just four years ago, that would have been enough for all applications across the whole world.

However, the total cost of ownership of an electric vehicle compared to a vehicle with an internal combustion engine is still two or three times higher due to the costs of their batteries. That is why all the big producers are adding capacity in part because it drives down unit costs. Lithium-ion cells (the basic components of batteries) cost over $1.000 a kilowatt-hour in 2010, last year they were in the $130-200 range (Economist 2017). Lower costs are not only improvements, large amounts of R&D investment have led to better power density (more storage per kilogram) and better durability (more discharge-then recharge cycles). Moreover, there is no doubt that electric vehicles are getting better and cheaper. But the constraints on their charging are still major factor for considering to adopt an EV. As an example, in Britain 43% of car owners do not have access to off-street parking and thus aren’t able to charge them at home (Bonges and Lusk 2016). Possibly, like petrol stations, the answer will be fast-charging stations as a way how some car companies are beginning to build them in order to assuage the “range anxiety” that turns some drivers off electric vehicles.

Building a vast charging infrastructure is a major point in the electric vehicle’s deployment. The following table shows the development of the number of publicly accessible charging positions in the European Union.

Number of publicly accessible charging positions



What could be seen from the chart (EAFO 2017a) above is the fact that the charging infrastructure is becoming widely available throughout the European Union. But besides the number and distribution, the types of charging points have also a major role. Several European studies concluded that, in most scenarios, it is possible to ensure everyday mobility using only common electric vehicles charging overnight at home. But such conclusions focus only on everyday mobility in urban areas and disregard long-distance trips (Hall, Moultak, and Lutsey 2017). Moreover, consumers remain concerned that electric vehicles have a limited range. This explains probably also the fact why the number of high-power charging stations have a positive growth from 2014. By installing infrastructure that recharges vehicle batteries quickly, long-distance trips would be also accommodated.

# 3 The Effect of Policy Incentives on Electric Vehicle Adoption

## 3.1 Electric Vehicle Market

Higher electric vehicle sales are crucial if manufacturers are to reach tougher emissions targets. Electric vehicles can decrease the dependence of the transport sector on fossil fuels, which has environmental advantages. Moreover, a decrease of local exhaust emissions can increase the air quality and decrease health problems that are related to air pollution (Green, Skerlos, and Winebrake 2014). On a global level, EVs decrease the $CO_2$ -emissions related to personal transport. In this regard, statistical look of the European EV market will be taken in order to get a better understanding of how fast the attractiveness and deployment of the EVs is developing.

Europe marks year 2013 as an important momentum with sales of electric mobility moving beyond the margin of 1% in some countries. On the regulatory side, the European Commission shows support for the further adoption of electric vehicles by proposing a directive on the deployment of alternative fuels infrastructure in January 2013 which explicitly supports clean fuel transport and proposes specific targets on enabling infrastructure deployment. At a more granular level, in the same year several European countries are seeing remarkable growth rates. Norway is the clear market leader with EVs adding up to 6.2% of the total car sales in 2013. Country’s share of EVs in new sales reaches 12% of new vehicle registrations in November 2013 (1.434 of a total of 12.079) (McKinsey 2014).

In 2017 Plug-in vehicle sales in Europe is 307.400 units, 39% higher than for 2016 including all Battery Electric Vehicles (BEV) and Plug-in Hybrids (PHEV) in the passenger cars and light commercial vehicle categories. The Plug-in share of the European light vehicle market reaches 1.74% for the same year, the share is over 2% during the last 4 months and reaches 2.55% in December. The top-5 plug-in models in Europe are Renault Zoe EV, BMW i3 EV/EREV, Mitsubishi Outlander PHEV, Nissan Leaf EV and Tesla Model S. Pure EVs (BEV) stands for 51% of the volume, PHEVs for the rest. A mere 174 units of Fuel Cell Vehicles is delivered, 40 units more than 2016 (Database 2017).

In general, almost all European countries post strong growth rates for 2017, many of them in triple digits. In 2018 around 430.000 Plug-ins are expected to be delivered in Europe, 41% more than in 2017. This translates to 2.4% share in a total European light vehicle market, expected to reach 18 million sales. In Norway, where Plug-in shares are the world’s highest, with 32.5% in 2017, BEV and PHEV combined, a clear highlight on the market could be seen. In December 2017, Norway reaches 42% and, counting only passenger cars, 50% of December

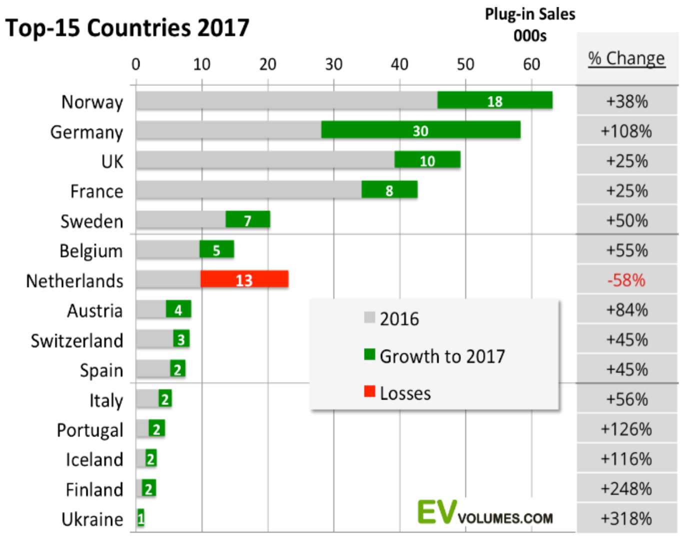


Table X

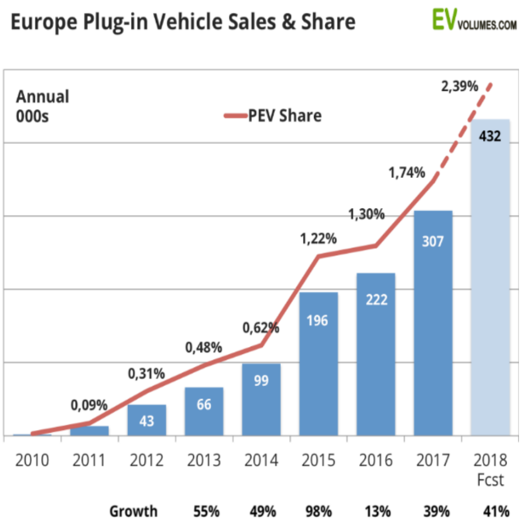


Table Y

sales are electrically chargeable vehicles. Moreover, compelling savings on vehicle taxes, toll exemptions and a well-developed charging infrastructure pave the way for the mass adoption of Plug-Ins. For 2025, the plan is to ban sales of fossil fuel vehicles altogether, in Norway (Table X). In comparison, Portugal also ranked among the 15 top countries deploying EVs, reaches around 5.000 EVs (BEVs and Plug-ins), showing around 130% positive growth in 2017 (Database 2017).

To sum up, the European sales history shows a consistent trend towards higher plug-in sales for the last 7 years. Table Y contains an anomaly in 2015 and 2016 when a 2-step reduction in tax incentives for PHEV in the Netherlands causes a run on these vehicles at the end of 2015. This is followed by a drastic decline in PHEV sales in 2016, another spike in Q4 and a further slump in 2017. Netherlands Plug-in sales contracts from 43.300 units in 2015 to 9.700 within 2 years. Still, European Plug-in sales increases by 39% last year, 1/3$^{rd}$ can be attributed to growth in Germany (Database 2017). The projection for 2018 is another 41% increase to around 430.000 units. This assumes that incentives remain on current levels and that supply meets volume demand.

The article “Electric Vehicles in Europe Gearing up for a new Phase” 2014 shows the McKinsey research about the main drivers of the adoption of electric mobility in Europe which are consumer demand, industry developments and government stimulus (McKinsey 2014).

Consumer demand as a first force explains what incentivise people to switch from a vehicle with ICE to an electric one. The research on early EV adopters in megacities (Shanghai, New York, and Paris) shows that this group represents mainly higher-income consumers with a distinct set of attitudes and behaviours. Furthermore, these observations are in line with the findings in Norway, where early adopters are in the main high-income, well-educated consumers, and also those, who are concerned about the environment.

Therefore, despite the various factors such as design, brand, and performance, which are all essential consumer considerations, there are three key motives for early EV adoption:

- Carbon footprint reduction is a primary motivator for environmentally conscious consumers to buy EVs.
- Driving and usage benefits include preferential parking permits in dense urban areas or the ability to drive in bus and taxi lanes are additional benefits offered by many governments and cities in an effort to stimulate EV sales.
- Cost savings are results of government subsidies, which in many cases include exemption from purchase tax, VAT, toll road charges, registration tax, and annual circulation tax, and also provide a cheap mobility solution in the recent period of high fuel prices in Europe.

Industry developments are another driver for consumers to buy an EV. The number of EV releases, including hybrids is increasing every year since 2010, making EVs more attractive and available to a larger audience. Technological advancements and cost reductions across the EV value chain are beneficial for EV adoption. As previously discussed, a good example is the charging system (slow and fast chargers) which has become standardized, and costs getting down due to the growing economies of scale. Further, OEMs (Original Equipment Manufacturer) and suppliers are investing more in EV production platforms, bringing overall EV manufacturing costs down further (Al-Alawi and Bradley 2013).

Government stimulus are the third main driver for incentivising EVs deployment. On both, the demand and supply side governments are promoting EVs across Europe by providing a range of subsidies and other benefits  (Langbroek, Franklin, and Susilo 2016). One of the key reasons is the reduction of $CO_2$ emissions. The EU's $CO_2$ reduction targets for transport are ambitious compared to the US, Japan and China aiming for 95g $CO_2$ /km cap by 2020 and regulations are likely to further tighten beyond 2020 (McKinsey 2014). Due to these restrictions OEMs are getting pressured to reduce their fleet emissions (on average 28%). Similarly with $CO_2$ , regulation of NOx emissions are also tightening with the EU Air Quality Directive of 2008. Moreover, steps for promoting electric mobility are taken in cities, which are one of the prime centers of air pollution and which will be threatened with EU fines if they do not improve.

Another boost for EV growth from the governments of major European countries comes from the desire for higher energy independence and a shift towards a less oil-intensive transport sector (Bakker and Jacob Trip 2013). With the aim to pioneer the technology and keep the value chain in the country, governments in countries with leading OEMs are prioritizing the development of EV technology.

## 3.2 Policy Incentives for Electric Vehicle Adoption

Although the European EV market shows a constant positive growth, the uptake of EVs is still relatively low. In general, main reason for the slow deployment of EVs is that these vehicles have a comparatively high investment cost due to the high cost of batteries (Newbery and Strbac 2016). In order to increase the attractiveness of electric vehicles, packages of policy incentives are provided in many countries. As policy measures intervene with the generalized costs of EV-use, they can be considered as attributes of EVs that can be influenced by governments.

### 3.2.1 Policy Measures Types

- Purchase-Based vs. Use-Based

In general, there are two different kinds of policy measures – purchase-based and use-based. Purchase-based policy, for instance, is a subsidy when buying an EV or a tax rebate when registering an EV. Examples of use-based policy are the providing of free parking slots for EVs, the allowance for users to drive in bus lanes or the providing of congestion charging exemptions for EV users. Purchase-based incentives decrease the fixed costs of EV-use, while use-based incentives decrease the marginal cost of EV-use.

In general, policy incentives can be of a local or global kind. On the one hand, local policy incentives such as free parking in a specific city or access to bus lanes are likely to only influence people who can gain from these location-specific incentives. On the other hand, global policy incentives such as national tax rebates (annual road taxes or vehicle registration tax) or subsidies apply to everyone in a country (Lieven 2015).

- Financial Incentives

Furthermore, to stimulate EV deployment, countries use financial incentives from both technology specific policies, such as subsidies to EV consumers, and technology neutral policies, such as emissions-based vehicle taxes, applied either at the time of a vehicle's registration or on its annual circulation fee. In some cases, countries decrease automobile taxes for EVs, and in others they provide subsidies apart from normal registration and circulation fees, thus presenting a very diverse financial incentive landscape (Sierzchula et al. 2014).

Therefore, based on the achieved countries' results, it could be noted how differently policy measures such as fuel taxes, consumer subsidies, and installing charging stations, could influence EV adoption. In addition, a model by Sierchula, 2014, provides an insight of the patterns that many of the EV-specific variables are strongly correlated to (price, year of introduction, availability, market share, financial incentives, and charging infrastructure), indicating that industrial dynamics can become interwoven during the early commercialization of a radical innovation. Another observation is that the EV price variable has a negative correlation to a country's market share.

Moreover, it could be seen from Figure 1 (Sierzchula et al. 2014) that financial incentives and EV deployment have a positive and significant relation one to another. In addition, there appears to be two groups of countries. The first represents around the half of the study sample (14 countries) with financial incentives less than \$ 2.000. It exhibits lower EV market shares with the exceptions of Sweden (0.30%) and Switzerland (0.23%), and to a lesser extent

Germany (0.12%), and Canada (0.13%). Accordingly, 10 countries show little EV activity as measured by either financial incentives, or EV adoption.

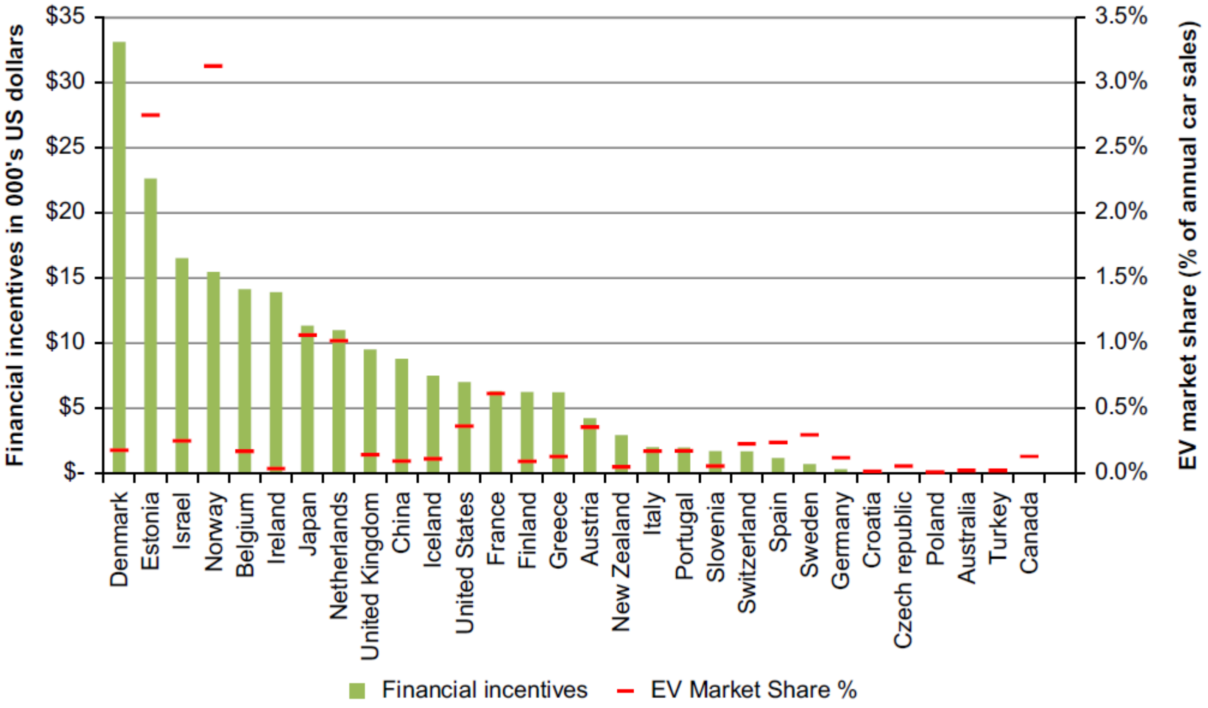


**Fig. 1.** Financial incentives by country and corresponding EV market share for 2012.

The other group is separated between countries with higher levels of financial incentives and bigger variation in their EV market shares. Some countries such as Norway match high financial incentives with increased EV adoption. However, this relationship is not uniform as other countries, including Denmark and Belgium, offered at that time high financial incentives but which, at the same time, have relatively low levels of adoption.

Additionally, to the variables captured by the model, there are likely to be country-specific factors that influence national EV market shares. These country specific factors provide insight into factors not included in the model that have the potential to greatly influence national EV adoption levels. Moreover, Figure 1 suggests that there are factors other than financial incentives that drive EV adoption (Gärling and Thøgersen 2001). For instance, Norway installed extensive charging infrastructure in 2009, and has experienced a more gradual increase in EV adoption rates since 2010, predominantly through household consumers (Hall, Moultak, and Lutsey 2017).

- Types of Financial Incentives

Based on the vehicle’s tonnage, company car status, emissions, and powertrain, countries employ several different financial incentives, which can be categorized as either registration or circulation subsidies. Figure 2 notices that broadly available EV financial incentives (78%) come in form of registration as opposed to circulation subsidies. The differentiation between the two is that registration funds are offered the year that the EV is purchased while those based on a vehicle’s annual circulation provide benefits over a multiple year time span. Main reason why registration subsidies are dominant form of financial incentives is due to the consumer high discount rates for circulation subsidies, effectively lowering their perceived value (Sierzchula et al. 2014)

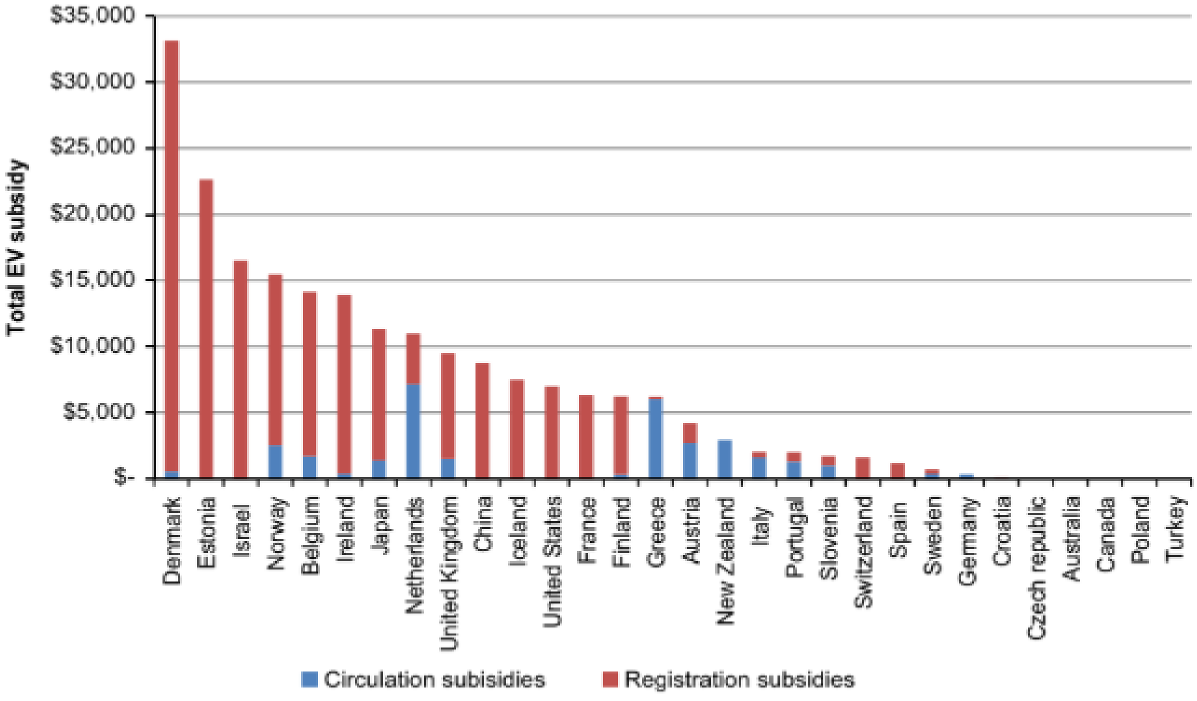


**Fig. 2.** Breakdown of financial subsidies types offered by countries.

.

Next, although not as much information is available about national charging infrastructure as financial incentives, perhaps because in many countries they are largely installed by local municipalities (Bakker and Jacob Trip 2013), Figure 3 (Sierzchula et al. 2014) exhibits a positive and significant relationship between charging stations (adjusted for population) and EV adoption rates. Despite an overall positive correlation, there are examples of wide discrepancies in the data as evidenced by Estonia and Israel. Both countries have similar charging station proportions, but Estonia shows an EV adoption level 11 times higher than that of Israel.

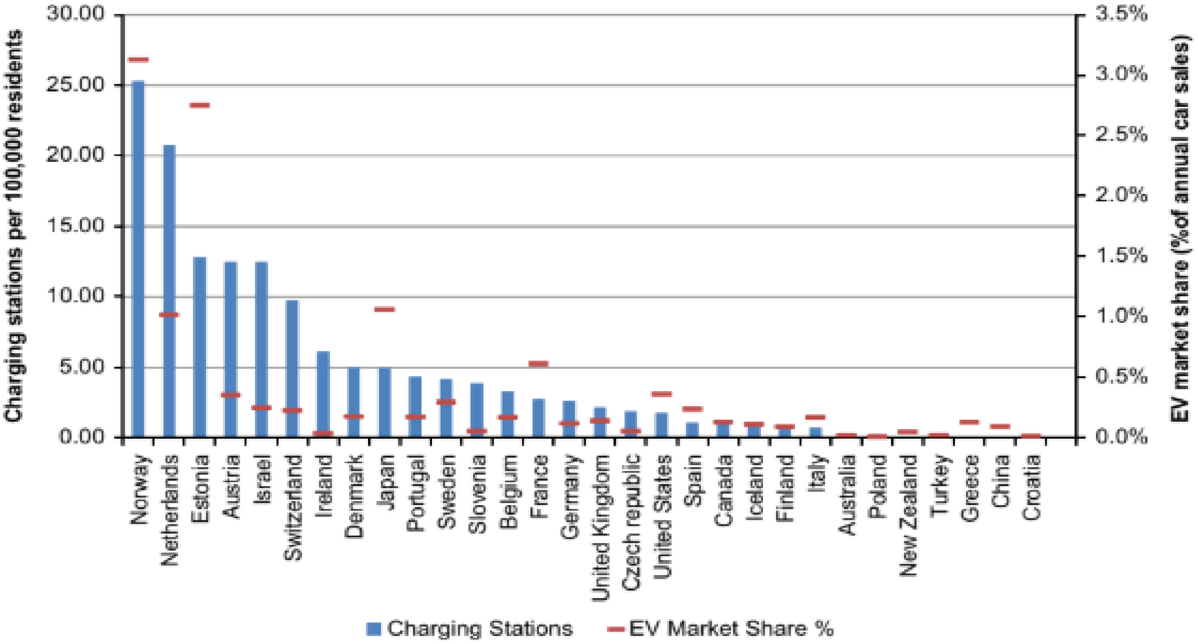


**Fig. 3.** National charging infrastructure by country and corresponding EV market share for 2012.

Figure 4 sums up the results, observed in the Figures 1, 2 and 3, and shows that five out of the 30 countries have very slight activity during the introductory phase of EVs, as measured by financial incentives, adoption, or charging infrastructure installation. Therefore, countries in this study could be separated into two groups with divergent attitudes toward EV adoption as reflected by government policy and consumer purchase behavior. One set of countries seems to be actively engaged in the EV introductory market while the other appeared to show very little interest.

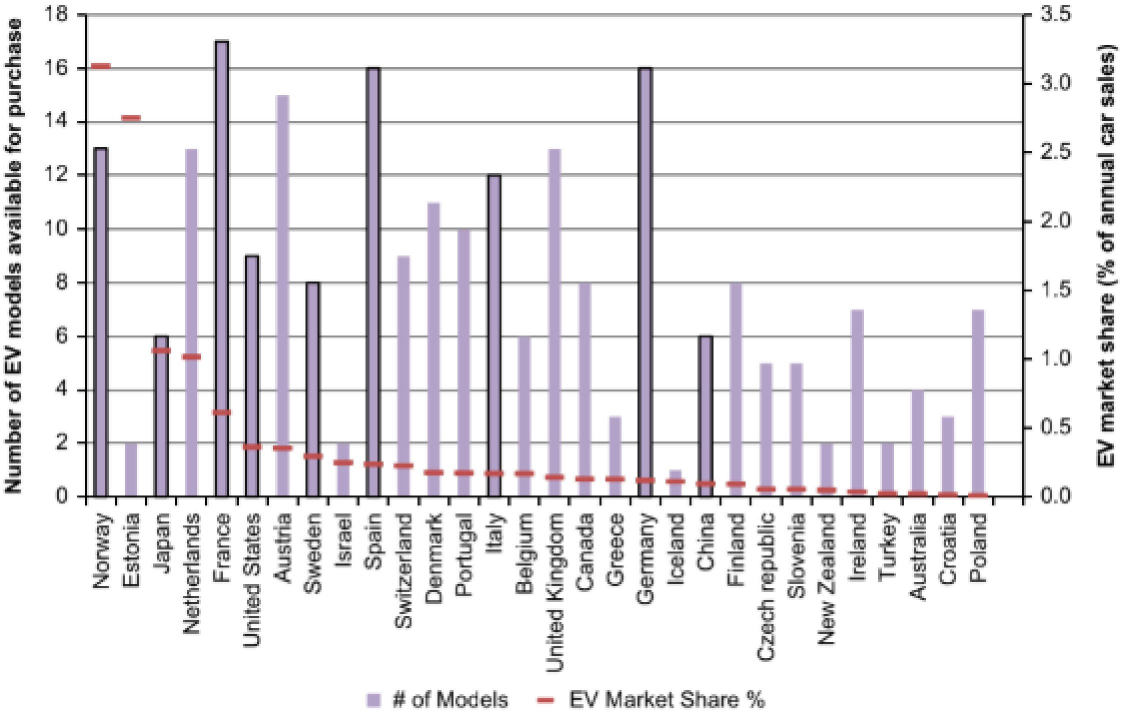


**Fig. 4.** Number of EV models available for purchase, production facilities, and national market shares.

However, the difference between the two groups will likely have little effect on the overall success or failure of EVs as the countries invested in their adoption represent a substantial majority of global GDP based on national purchasing power parity (The World Bank 2014). Another important remark, observed by the model is that there is a positive correlation between a country's EV adoption rate and the number of models that are available for purchase. Thus, countries where native manufacturers heavily invest in EVs e.g., Japan, France and the US, have some of the highest EV market shares. Other countries with EV production facilities but low adoption rates including Germany and Italy do not have EVs made by native manufacturers broadly available. Therefore, a strong relationship between consumer adoption of EVs and their being manufactured by native firms. This relationship between the variables in Figure 4 suggests a complex relationship between consumers, manufacturers, and national attitude regarding EVs (Sierzchula et al. 2014).

Also, another essential point, based on the empirical results of the model, is that while charging infrastructure and financial incentives are significant in predicting EV adoption, this is not the case with broader socio-demographic variable e.g., income, education, environmentalism, and urban density (Gallagher and Muehlegger 2011). Main reason for that is the relatively small size of national EV markets compared to overall automobile sales. Thus, while many EV consumers may have high levels of education and be passionate about the environment, within the perspective of a country such individuals still represent a tiny portion of the overall population (Sierzchula et al. 2014). Therefore, socio-demographic variables do not provide a good indicator of adoption levels when comparing countries. Additionally, despite its strong and positive correlation to HEV adoption, fuel price is neither significant in predicting a country's EV market share. In this regard, more research is necessary to discover the relationship between fuel price and EV adoption, specifically studies that span multiple years and look at a single country (Lane and Potter 2007).

### 3.2.2 Factors influencing EV Adoption

Currently, a number of federal policies are in place to incentivize deployment of PEVs to mainstream consumers with demographics and vehicle attribute preferences most common to today's new vehicle purchasers. Main reason is that Plug-in electric vehicles provide an opportunity for reducing energy use and emissions in the transportation sector. Apart from that, EVs are introduced to the broader consumer market only recently in 2010, which explains why there is little research that uses empirical data to analyze factors which affect EVs' adoption rates. Despite that, HEVs provide a good comparison basis for EVs (even though they are less of a radical innovation) because they have several of the same key elements including a battery and electric motor based powertrain and lower environmental impacts (Lane and Potter 2007). As HEVs have been commercially available since 1990s, there are several studies that use revealed preference data to investigate factors that influence consumer uptake for those automobiles. Based on the findings in HEV revealed preference research, EV survey studies, and theoretical articles, factors have been collected and categorized that are assumed to determine the decision of whether or not to purchase an electric vehicle (Diamond 2009).

- Differentiation of Target Groups

In a study, based on a stated-choice experiment, which uses constructs of the Transtheoretical Model of Change (TTM) and the Protection Motivation Theory (PMT), the effect of several potential policy incentives on EV-adoption as well as the influence of socio-psychological factors are being investigated in order to see what determines the probability of EV deployment increase. Most policy incentives making the EVs more attractive are targeting all car drivers, without any distinguishing, although different traveller groups have different preferences. So that in order to distinguish the different groups of travellers based on their stated preferences and demographics, a study by Lieven uses cluster techniques and compares the effect of policy measures on the travellers and further, if they react differently to those policy incentives (Lieven 2015). What is more, considering behavioural change as a process, different car drivers are in different stages-of-change towards electric vehicle use. They have diverse attitudes towards sustainable transport and electric vehicles in particular and diverse needs depending on where they live. All of these perspectives influence EV adoption, as well as the responsiveness to policy measures (Langbroek, Franklin, and Susilo 2016).

- Intrinsic vs. Extrinsic Motivation

At an early EV deployment stage it is understandable that people won't be aware of the characteristics of a new product such as electric vehicle. Those characteristics depend on the current state of technology and the choices that different car manufacturers have made. The electric vehicle itself is a product that has some features such as certain design, speed, comfort level, price and range. This core product, as well as the characteristics of the potential customer, provides some intrinsic motivation for somebody to purchase an EV. Additionally, intrinsic motivation is defined as an actual and internal tendency to perform an action, while extrinsic motivation is about a separable consequence that is separate from the actual action (Ryan and Deci 2000). Policy incentives such as subsidies, tax rebates or congestion charge exemptions influence the generalized cost of EV-use and therefore influence people's extrinsic motivation to switch to EV-use.

On the other side, the amount of policy incentives that a specific person needs to be convinced to start using an electric vehicle, depends on this person's intrinsic motivation level. A person that would buy an EV regardless of whether any policy incentives are offered, has high intrinsic motivation to buy an EV, while other people might only be interested in purchasing EVs if they would have been offered huge amounts of benefits (Langbroek, Franklin, and Susilo 2016). Rezvani et al. (2015) claims that the intrinsic motivation of someone to start using EVs depends on personal aspects and on attributes of the EV. Also, other factors such as technological, social, personal, and cost factors that have an influence on electric vehicle adoption are identified (Rezvani, Jansson, and Bodin 2015).

Based on a survey among active drivers in the city of Stockholm, in which socio-cognitive constructs from the Protection Motivation Theory and the Transtheoretical Model of Change have been included, it has been shown that stages of change towards electric vehicle adoption are correlated to both socio-economic characteristics, and socio-cognitive constructs such as knowledge, attitudes and self-efficacy (Langbroek, Franklin, and Susilo 2017). Due to differences between these groups with respect to their position in the process of behavioral change towards electric vehicle use, it is assumed that people in dissimilar groups also react differently to policy incentives offered. While some people tend to get more information about the characteristics of electric vehicles and tend to have an ever increasing self-efficacy towards using EVs, some policy instruments might, for instance, have a larger or smaller influence on people that are already considering buying an EV. People who are currently using EVs might have an even higher intrinsic motivation to buy a second EV in the future, so that they depend less on policy incentives. However, it is questionable whether they are also unequally responsive to policy measures that can be taken in order to increase the attractiveness of EVs. More insight into the effects of policy measures on people that are in different stages-of-change can contribute to more insight into EV adoption strategies (Rezvani, Jansson, and Bodin 2015).

- Price, Driving Range and Charging Time

The technology category sums up aspects of electric vehicles including battery costs and performance characteristics (driving range and charging time). The most significant obstacle to widespread EV diffusion are EV purchase prices, which are heavily dependent on battery costs (Brownstone, Bunch, and Train 2000). The IEA (2011) finds out that the buying price of an EV with a 30kWh battery (approx. 85 miles of driving range at 0.17 kWh/mile) would be $10.000 more than a comparable ICEV. Battery costs also have an impact on the driving range of an EV. An increase in the size of an EV’s battery (in kWh) raises both its purchase cost and driving range. Therefore, although consumers are sensitive to a limited driving range (Lieven et al. 2011) that aspect must be balanced with its relation to vehicle battery costs.

Another factor influencing consumer adoption is vehicle’s charging time (Hidrue et al. 2011). Whereas most ICEVs are able to refuel in about 4 min, EVs require approx. 30 min at a fast charging station and up to several (>10) hours for charging from a 110 or 220 V outlet, dependent on battery size (Saxton 2012). Relative to a comparable ICEV, an EV’s high purchase price, limited driving range, and long charge period all have a negative impact on adoption rate.

Additionally, consumer characteristics also play a role in determining the EV’s uptake. A study points out levels of education, income, and environmentalism to all be positively correlated to likelihood to purchase an EV (Hidrue et al. 2011). However, these factors, specifically environmentalism, are rarely important to consumers than vehicle cost and performance attributes such as those identified above (Lane and Potter 2007).

- Context Factors

A third set of elements, categorized as context factors also influence adoption rates and is external to both the vehicle and consumer. A study by Diamond (2009) identifies fuel (gasoline or diesel) prices as one of the most powerful predictors of EV adoption (Diamond 2009). Also, despite less commonly incorporated in analyses, related to fuel prices are electricity costs. Those two factors combine to determine a majority of EV operating expenses which in turn have an impact on adoption rates (Dijk, Orsato, and Kemp 2013). Other studies identify availability of charging stations as an important determinant in consumer acceptance of alternative fuel vehicles (Tran et al. 2012; Egbue and Long 2012). A country's level of urban density could facilitate greater EV adoption as shorter average travel distances might allow for wider use of the vehicles' limited driving range (International Energy Agency 2017b).

- EV's Specific Factors

Finally, there are several factors specific to EVs that could influence adoption rates including vehicle diversity i.e., the number of models that consumers can buy, local involvement i.e., the presence of a local manufacturing plant, and public visibility i.e., the number of years EVs have been available for purchase (Sierzchula et al. 2014).

In a study by Sierzchula, Bakker, Maat and Bert van Wee (Sierzchula et al. 2014) data from 30 countries for 2012 is collected and analyzed because of the availability of data, specifically EV adoption and charging infrastructure figures. The electric vehicles are defined as including both pure battery electric vehicles, as well as plug-in hybrid electric vehicles.

Based on the factors previously discussed, data for the following variables for each country is observed: EV market share, financial incentives, urban density, education level, an environmentalism indicator, fuel price, EV price, presence of production facilities, per capita vehicles, model availability, introduction date, charging infrastructure, and electricity price. EV adoption is operationalized as national market share of electric vehicles.

- Effectiveness and feasibility of policy incentives

The effectiveness of policy incentives, as well as their feasibility are assumed to depend on the scope and timing of incentives. Important fact is that currently many people are not aware of electric vehicle's technology, its possibilities and its limitations, nor of the package of policy incentives which are available, which makes them less likely to adopt an EV. In this regard considered as effective are those incentives, which substantially increase the probability of buying an electric vehicle. If they do not increase EV adoption, they will only redistribute income. In a study by Zhang (Zhang, Yu, and Zou 2011) it is assumed that policy incentives for EVs in general have a positive effect on EV adoption. Furthermore, feasibility of policy incentives consists of an evaluation of the financial, social and political costs of policy measures (Bakker and Jacob Trip 2013). For some measures it is hard to get political and public support for implementing particular instrument, even though they might be very effective.

## 3.3 Differentiation of Policy Incentives Impacts

### 3.3.1 Policy Focus on Niche Early Adopters

Essential stimulus for the governments to stimulate the EV deployment is the fact that Plug-in electric vehicles (PEVs) provide an opportunity for reducing energy use and emissions in the transportation sector. Currently, a number of federal policies are in place to incentivize deployment of PEVs to mainstream consumers with demographics and vehicle attribute preferences common to today's new vehicle purchasers.

However, policies focusing on mainstream consumers are proven to be inefficient and ineffective. Instead, policies intending to give PEVs a foothold in the market should focus on early adopters including green consumers and on niche markets – specifically car sharing (Green, Skerlos, and Winebrake 2014). Green, Skerlos, and Winebrake (2014) note three categories in which policies encouraging PEV adoption fall: (1) research and development (R&D), (2) investments in charging infrastructure and electric vehicle service equipment (EVSE), and (3) vehicle tax credits or rebates. Despite the fact that these policies are intended to address the primary barriers to mainstream PEV adoption, it is argued that each category of PEV policy includes a mainstream market bias that threatens the ability of these policies to achieve the intended aim.

Firstly, there is the US EV Everywhere initiative in the US, which has a goal of producing PEVs with “sufficient range and fast-charging ability to enable average Americans everywhere to meet their daily transportation needs more conveniently” by 2022 (US Department of Energy 2013). Moreover, substantial resources are being invested in order to meet the ambitious mainstream market targets (Congress approves $330 million in funding for battery and vehicle research) such as a battery that will go 300 miles on a single charge. But for all that, in order for such investments to be justified, PEVs must rival conventional vehicles in all respects proving to be viable market contenders. Conversely, advancements in PEV performance to achieve mainstream market penetration often fail to reduce costs in the short term, thereby pricing them out of reach for most consumers (Axsen and Kurani 2011). More importantly, these investments crowd out other investments that would bring more basic PEV designs to market, and which ultimately could be more attractive for early adopters. For instance, it has been found that potential early adopters chose lower-performance PEV battery designs than those assumed by experts, and that their expectations could be met with existing battery technology (Axsen, Kurani, and Burke 2010).

Secondly, in order to meet the needs of mainstream PEV drivers, a dense network of charging stations is required. This assumption derives from experience with other alternative fuel vehicles (AFVs), which faces the “chicken-and-egg” problem. Furthermore, people will not purchase AFVs without adequate fueling infrastructure, and fuel providers will not invest in infrastructure until a critical mass of AFVs is achieved (Melaina and Bremson 2008). However, “chicken-and-egg” does not quite apply to early PEV markets since the charging infrastructure is fundamentally different than other AFVs. As observed, “range anxiety” is more psychological than physical, and pilot programs in Europe show that public charging infrastructure is rarely used (Smart and Schey 2012). As a matter of fact, in most EV Project cities each publicly accessible Level 2 EVSE is used on average once every 5-10 days (0.1-0.2 charging events per day – compared to 0.9 charging events per day for residential Level 2 EVSE), and DC Fast Chargers are used less than four times per day on average – effectively 5% of the time available (Wishart et al. 2013; Kley, Lerch, and Dallinger 2011). Therefore, investments in public PEV charging infrastructure offer marginal value in realizing the intended benefits of PEV adoption. So, in effect millions are spent on public EVSE to alleviate mainstream consumers’ range anxiety, while failing to considerably increase PEV adoption.

In general, to encourage PEV adoption, more cost-efficient and effective policies are needed, which focuses on making PEVs accessible to consumers and markets valuing the specific characteristics of PEVs, rather than attempting to alter PEV technology prematurely to earn attention by mainstream consumers. It is necessary to eliminate mainstream market bias and consider to target audience of early adopters who care about the environment and are willing to accept tradeoffs in features and price in order to achieve the energy and environmental benefits of driving a PEV (Axsen and Kurani 2011; Lieven et al. 2011). Therefore, increased PEV market penetration and achievement of societal benefits will likely occur more efficiently by focusing policy mechanisms on niche opportunities created by the unique characteristics of PEVs. In doing so, policy strategies could be identified that are more cost-effective and conductive to meeting societal targets of decreased emissions and energy consumption.

### 3.3.2 Strategies

Strategic niche management (SNM) is a means to introduce innovative technologies into the marketplace by simultaneously addressing technical, policy, social, production, and infrastructural barriers. The SNM approach aims for sustainable diffusion of technology by identifying niches where the unique strengths and benefits of a technology are maximized, and where any barriers and challenges are minimized. As a result SNM provides the concentrated focus, learning, and social networks necessary for a self-sustaining diffusion of technology (Axsen and Kurani 2011).

### 3.3.3 Car Sharing

As an appropriate technological and market niche for PEVs, policy support for car-sharing using PEVs, along with associated targeted infrastructure, would synergistically benefit both objectives while potentially increasing cost-effectiveness of government PEV deployment support. This proposal it is supported by several findings. For example, car-sharing organizations (CSO) eliminate the purchase price burden of PEVs for members, reduce automobile operating costs, and address range anxiety by allowing members to choose a car “fit for the trip” (e.g., a PEV for shorter trips and a conventional or hybrid vehicle for longer trips (Kley, Lerch, and Dallinger 2011; Dijk, Orsato, and Kemp 2013). Moreover, car-sharing also mitigates the barrier of limited charging infrastructure, providing charging in central facilities or designated on-street parking, and thereby making PEVs accessible to millions of households where at-home charging is not possible. Car-sharing essentially furthers the societal goals of PEVs. While reducing vehicle ownership by 50%, CSOs reduce also vehicle miles traveled by 8-80% along with GHG emissions by 27-43% (Kriston, Szabó, and Inzelt 2010). So PEVs use in urban areas may result in greater health benefits compared to use in rural areas (Skerlos and Winebrake 2010).

Another essential point supporting the benefits of car-sharing demand is the result of the sustainable markets. CSOs appeal to social activists, environmental protectors, and innovators who indicate willingness to pay more to use zero-emission vehicles – at a premium that will result in positive profits for CSOs (Kriston, Szabó, and Inzelt 2010). Also, public investments in CSOs would be comparably cost-effective, as the cost of each vehicle is spread among a bigger number of drivers, ensuring higher utilization (Shaheen and Cohen 2012).

Consequently, targeting PEV policy mechanisms toward car-sharing organizations would result in multiple self-reinforcing benefits such as financial incentives, which cover the vehicle incremental costs or infrastructure installation in CSOs; incentives for establishment of CSOs in cities and towns where systems currently do not exist; and, incorporating PEVs and charging infrastructure into government fleets where car-sharing exists (Luè et al. 2012).

### 3.3.4 Markets Focus on Early Adopters

Another strategic niche would be that the government target incentives at early adopter markets and “green consumers”. Typically, early adopters are interested in PEVs for their efficiency and environmental performance rather than the advanced technology or other offerings, because green consumers are more likely to accept tradeoffs in vehicle features in order to achieve these benefits (Luè et al. 2012).

Moreover, Axsen et al. (2011) elicits PHEV designs from perspective buyers, noticing that most of them chose vehicles with the least all-electric range and the lowest cost. This finding concludes that in the short term policymakers could focus on bringing down the cost of PEVs by identifying the performance, features, and costs acceptable to early adopters and most ideal niche markets, which may differentiate substantially from current designs or government targets. Focusing on early adopter niches rather than the mainstream market may also allow elimination of superfluous amenities, thus making PEVs financially accessible to early adopters who are willing to make such tradeoffs. Another essential point here is that accessories and features are not only costly, but often detract from environmental performance by increasing vehicle energy consumption (Kemp, Schot, and Hoogma 1998).

### 3.3.5 High-End and Low-End Early Adopters

The majority of EV deployment data is gathered from studies that sample members of the general population and not actual EV adopters. In order to better understand where the market for those vehicles lies and also how to ensure that BEVs appeal to these markets, a deeper investigation of the profiles of early adopters is needed (Schuitema et al. 2013). This will inform policy makers and automotive OEMs on how best to grow the market of BEVs such that the societal benefits can be maximized. Because of the infant stage of EVs' research with recent market introductions beginning in 2008-2010, the majority of data is gathered from studies that sample members of the general population and not actual adopters of the vehicles. A study by Hardman, Shiu and Steinberger-Wilckens (2016) presents findings from 340 adopters of battery electric vehicles. Although the data used corroborates some existing assumptions made about early adopters, essential point of it is the distinction between two groups of adopters – high-end and low-end BEV adopters due to their differences in socio-economic and psychographic profiles (Hardman, Shiu, and Steinberger-Wilckens 2016).

Moreover, the majority of the present studies regarding BEV deployment overlook potential differences between high and low-end adopters, considering all the electric vehicle buyers as one homogenous group. For instance, a significant change in the landscape of the BEV market occurs in 2012 with the introduction of the Tesla Model S. Prior to that all BEVs on the market are considered as low-end electric vehicles with prices of $30-40,000 and ranges of <100 miles (Nissan Motor Co. 2012). The Tesla Model S, which is considered as a high-end BEV, costs $70-105.000 and has a range of 270 miles (Tesla-Motors-Inc 2015). Therefore, its introduction results in a creation of a new market segment. In this regard the study suggest that both groups are different due to the significant differences in the price and features of the vehicles, differences between their socio-economic and psychographic profiles, preferences, as well as differing intentions of future BEV purchase.

Due to the fact that at the end of 2014 there are 665,000 BEVs deployed globally with the US being at the top three of the markets for BEVs (39%), achieving a 1% share of 2014 vehicle sales (International Energy Agency 2017b), most of the early BEV adopters, which are being interviewed, are from the US. Kurani et al. (1994) explores characteristics of potential early adopters by interviewing multi-car households in the US. He presumes that the early adopters are households with two or more cars and have a garage where at least one car could be parked. Moreover, it is found out that the main advantages of BEVs are high fuel economy, low environmental impacts, positive image and BEVs being viewed as cutting edge technology (Kurani, Turrentine, and Sperling 1994). Even more, from the study's sample it is concluded that early adopters are likely to be highly educated, environmentally sensitive and would already tend to be owners of a hybrid vehicle. Studies by Gnann and Plötz et al. involving 210 people with "high interests in EVs" (Gnann and Plötz 2015) suggest that early adopters would be middle-aged males, in technical professions, in rural or suburban multi-person households. Another surveys predict that the early adopters are young, have green life styles, and fuel concerns, and own more than one car (Hidrue et al. 2011; Krupa et al. 2014; Campbell, Ryley, and Thring 2012). More, from a study trial with Mini E in the US data based on 54 Mini E drivers, using driving diaries, online questionnaires, and interviews, it is collected that users of the Mini E value the high performance of the vehicle, the sporty handling and the fact that these driving characteristics are available with low environmental impact (The Regeneration Consumer Study 2012). All of the study's members agree that BEVs are suitable for daily use, indicating that 71% of them are more willing to adopt a BEV after the trial. In addition to that fact, 64% of respondents indicate that they plan on purchasing a BEV in the next 5 years. However, a later study on the Mini E in Germany, which involves 79 participants in 6 month trial and which interviews them before, during and after the study, concludes that high purchase price and limited range still represent the main barriers to adoption (Bühler et al. 2014).

However, again, one of the most significant limitations of the literature is that early adopters are considered to be one homogeneous group of consumers. Unlikely, an adopter of a \$30.000 would be similar to the adopter of a \$105.000 vehicle. Therefore, main goal is the understanding of the differences between the socio-economic and psychographic characteristics of both groups, the understanding of how they respond to the vehicles that they adopt, as well as their future BEV purchase intentions. The results from this investigation reveal two distinct groups, which have significantly different socio-economic profiles. The first group are labelled as low-end adopters of BEVs, and the second one are the so called high-end adopters, who have higher incomes, higher education and also higher age. Essential difference between both groups is that high-end adopters have greater empathy and it takes them less time to adopt a new technology (Hardman, Shiu, and Steinberger-Wilckens 2016). High-end adopters also find image and brand to be of a benefit. Also, although both adopter groups agree that running costs, lifestyle fit, environmental impacts, fuel economy and performance are superior, and there are still statistically significant differences in the way how each group views these attributes. It is found, that high-end adopters do not believe their vehicles are worse than ICEVs in any area, but low-end adopters believe their vehicles have worse range, time to refuel and purchase price compared to an ICEV.

Also, after measuring, if each group has different future purchase intentions it appears that high-end adopters are likely to continue with BEV ownership with 81% continuing with BEV ownership in future purchases. Brand loyalty is also high with 64% stating their next vehicle will be the same make as their current one. Low-end adopters are less likely to continue with BEV ownership with 67% likely to continue with owning a BEV, moreover only 23% will continue owning a BEV of the same make as their current brand. Therefore 33% of low-end adopters may abandon the new technology with their next vehicle purchase, and 77% will choose a vehicle of a different brand, which could be harmful for the diffusion of BEVs and the creation of a more electrified transport system (Hardman, Shiu, and Steinberger-Wilckens 2016).

The results from this study are very useful making a number of policy and managerial implications strategically more successful. Furthermore, when introducing and promoting BEVs to markets, policy makers and OEMs should not view early adopters as one homogenous group, but targeting each high and low-end market differently. The results from the study of Hardman et al. (2015) proves that there are two distinct BEV adopter groups and that each group has a different socio-economic and psychographic profile. Moreover, when OEMs and policy makers are promoting either high or low-end BEVs they should target the correct markets for each vehicle due to the fact that they will respond to their vehicles differently and they will have distinct future purchase intentions. Therefore, the vehicle should address the right demographics, and should have the right attributes.

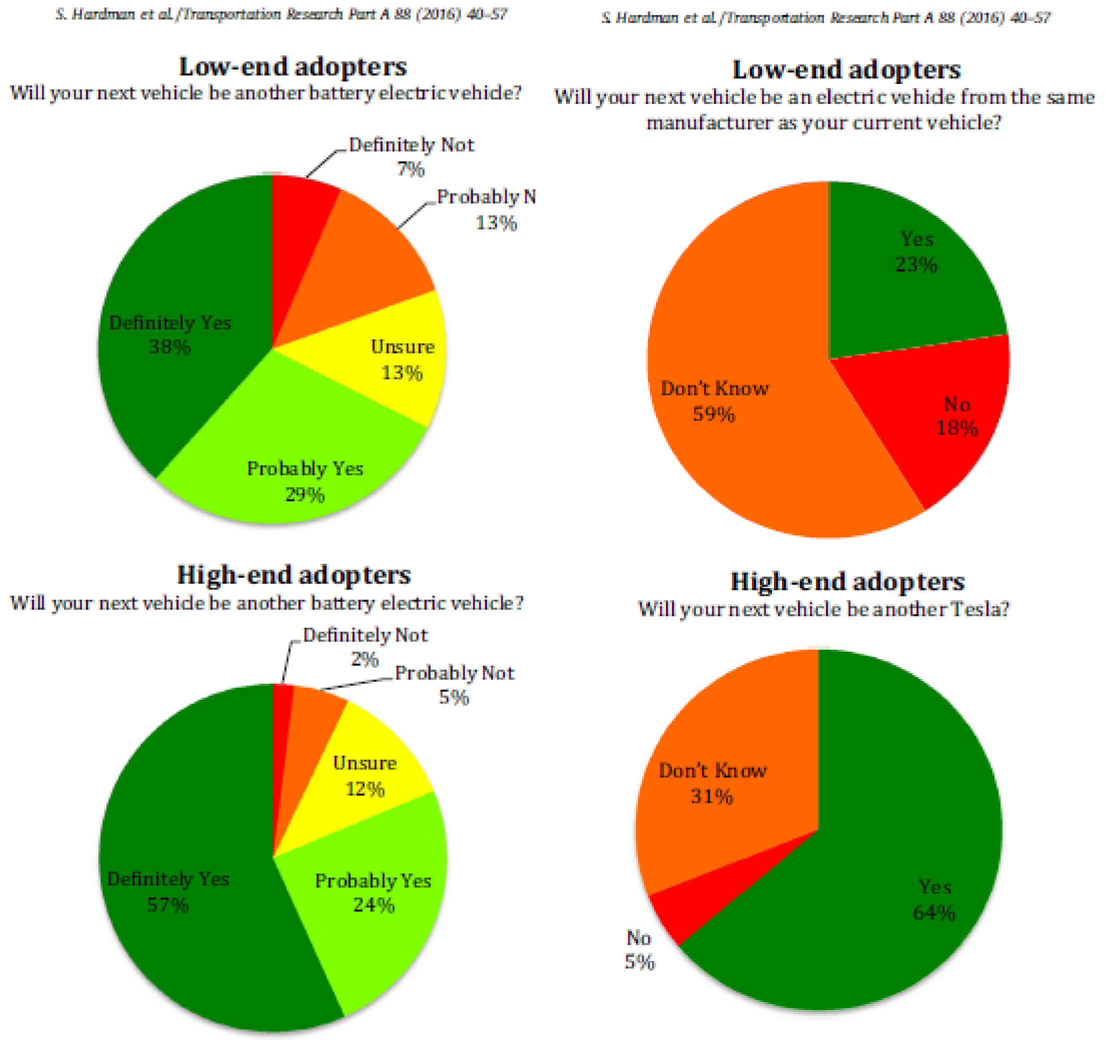


Fig. 2. Comparison of future purchase intentions of BEVs between low-end and high-end adopters.

Second essential implication of the particular study is that around to a third of all low-end adopters may abandon BEVs in their future purchases, because they have more shortcomings and therefore those low-end adopters may require more support to be convinced to accept the vehicles. Due to the fact that discontinuances could be damaging to the BEV market, a joint effort by OEMs and policy makers is needed to stimulate low-end customers to continue with their adoption decision. Also, if OEMs producing low-end BEVs can produce a BEV that is perceived by consumers as being similar to a high-end BEVs, especially for refueling time and range, then rates of adoption may increase and abandonment may not occur. Therefore, the priority will be increasing range and reducing refueling time, but it also will be beneficial to improve performance, brand perceptions and the vehicles looks (Hardman, Shiu, and Steinberger-Wilckens 2016).

## 3.4 Barriers Adopting EV

Making financing more accessible for PEVs would be another strategy stimulating the EVs adoption as the incremental cost of them is commonly accepted as a primary barrier. Generally, there are two types of financial barriers – ability to pay and willingness to pay (Skerlos and Winebrake 2010). As in some countries most people obtain new vehicles through financing rather than paying the full price upfront, the real cost difference for them would be the increased monthly payment, a large amount of which can be immediately offset or even eliminated with fuel savings (Al-Alawi and Bradley 2013). On the one hand, potential early adopters are more likely to be aware of PEV fuel savings, and willing to pay more for PEVs in order to realize fuel savings or environmental benefits. On the other hand, even if perspective buyers realize that fuel savings would bring monthly PEV ownership costs to an affordable level, the ability to pay could be hindered by the financing process, as many might not qualify for the higher loans associated with PEVs' greater upfront capital costs. Consequently, by incorporating fuel costs into auto loan approval criteria, PEVs and other efficient vehicles would be more financially accessible, while large, inefficient vehicles would be less accessible – extending the energy and environmental benefits of the policy beyond those directly attributable to PEVs. Governments might consider offering efficient vehicle loans, encouraging lenders to incorporate fuel economy into loan qualification calculations. Such loans would reach a larger market of eligible customers, would incentivize broad-scale GHG and energy use reductions, and would be less expensive than tax credits, furthering untapped opportunities in market mechanisms (Hidrue et al. 2011).

Also, as previously discussed, besides the fact, that customers are only willing to pay a limited price for being "green", the range limitations for the BEV configurations and energy availability of charging infrastructures are essential reasons, that may a potential buyer decide not to choose EV technology (Camus, Farias, and Esteves 2011).

# 4 A Policy Comparison between Norway and Portugal

After examining the different perspectives of a sustainable transport opportunity – the EVs, it is worth taking a deeper look into how countries are applying their policies in order to stimulate their electric vehicle fleet adoption. For this purpose a comparison between the undisputed global market leader – Norway and the still at its EVs deployment infant stage – Portugal, will be made with a main idea to get a better and real understanding about the pros and cons of the policies taken, and moreover, about their effectiveness and effectivity.

## 4.1 Norway

An issue of The Guardian from the 25th of December, 2017 reports that nearly a third of all new cars sold in the country in 2018 will be a plug-in model – either fully electric or hybrid, and it is expected that share to rise as much as 40% next year (Vaughan 2017). As a way of meeting its climate change ambitions the government of Norway drives the country's lead on electric cars, backing them with a wide range of generous incentives and perks. Moreover, for the drivers of these cars there is a simple motivation – "they just make financial sense". Buyers do not pay import tax and VAT on plug-in cars, saving thousands of pounds from the upfront cost. Also, running costs are lower because electricity is cheaper than petrol and diesel, while road tax is reduced and it is expected to drop "to zero during 2018". Furthermore, electric car owners do not pay the mosaic of road tolls, ferry fees and city emissions charges, which other Norwegians face. These drivers can also park for free and bypass traffic by driving in some bus lanes.

First, before taking a depth look into how the government of Norway applies its policies aiming to incentivize the EV fleet, a country's profile will be presented.

- Country’s Profile

Norway is a country located in Northern Europe occupying the western portion of the Scandinavian Peninsula as well as the volcanic island Jan Mayen and the Arctic archipelago of Svalbard. Norway borders the North Sea and the North Atlantic Ocean, west of Sweden. Its geography is rugged with steep fjords and mountains. The total area accounts for 323.802 sq km, which makes Norway the 69th country in the world by size.

The government system is a parliamentary constitutional monarchy, in which the chief of state is the king, and the head of government is the prime minister. With a population of around 5.320.045 people, most of which live in the south where the climate is milder and there is better connectivity to mainland Europe. The urbanization is high, with nearly 82% of total population living in cities, with 1.012 million people living in the capital Oslo, which makes the city the biggest in the country (CIA 2018a).

- Economy

Norway enjoys one of the world’s highest standards of living, having a stable economy with a vibrant private sector, a large state sector, and an extensive social safety net in large parts due to the discovery in the late 1960s of offshore oil and gas (News 2018). As a member of the European Economic Area, Norway partially participates in the EU’s single market and contributes sizably to the EU budget, although during a referendum in November 1994 Norway opts out of the European Union (CIA 2018a).

Due to its rich endowment with natural resources such as oil and gas, fish, forests, and minerals, Norway is a global market leader. The country is a major producer and the world’s second largest exporter of seafood, after China. Also, Norway is one of the world’s dominant petroleum exporters, although in 2000 oil production is close to 50% below its peak. Due to that fact, the government manages the country’s petroleum resources through extensive regulation. In 2016, although oil production is historically low, it rises for the third consecutive year due to the higher production of existing oil fields and to new fields coming on stream. Conversely, gas production doubles immensely since 2000. According to official national estimates, the petroleum sector provides nearly 9% of jobs, 12% of GDP, 13% of the state’s revenue, and 37% of exports. It is noticeable that for 2017 the oil production accounts for 1.979 thousand bbl/day, of which 1.255 thousand bbl/day are exported and just 228 thousand bbl/day leave for country’s consumption (The World Bank 2018a). Petroleum activities contribute significantly to economic growth in Norway, and to the financing of the Norwegian welfare state. Through over 40 years of operations, the industry creates values in excess of NOK 12.000 billion in current terms. In 2012, the petroleum sector accounts for 23% of value creation in the country, which is more than twice the value creation of the manufacturing industry and around 15 times the total value creation of the primary industries (Government.no 2013). Today, Norway is the world's third-largest natural gas exporter and seventh largest oil exporter.

Furthermore, in 2017 the GDP comes to $375.9 billion, which accounts for a growth of about 1.5% in the same year, driven largely by domestic demand, which is boosted by the rebound in the labor market and supportive fiscal policies. Moreover, it is interesting to be seen from the latest statistics of the CIA that 54.7% of country's GDP are actually revenues from taxes (CIA 2018a). Historically, after solid GDP growth in the 2004-07 period, the economy slows down in 2008, and contracts in 2009, before returning to modest, positive growth from 2010 to 2017. Additionally, economic growth is expected to remain constant or improve slightly in the next few years (The World Bank 2018a).

Regarding the country's labor force, statistics for 2017 show that the unemployment rate is nearly 4%, which is less than a year before (CIA 2018a). Another important measure for a country is how the income is distributed among the population. The Gini index is the most widely used measure of inequality. It looks at the distribution of a nation's income or wealth, where 0 represents complete equality and 100 total inequality (The World Bank 2018a). Using the most recent figures, in terms of income distribution – based on the Gini index estimates from the World Bank rank Norway as one of the most equal nations in the world (The Guardian 2017).

- Electricity

In 2016, Norway sets a new electricity production record of 149 TWh, 98% of which is produced by hydropower plats and wind farms. Norway has the highest share of electricity produced from renewable sources in Europe, and the lowest emissions from the power sector. Hydropower accounts for 96% of Norwegian power supplies, and the resource base for production depends on precipitation in a given year. This is significant difference for the rest of Europe where security of supply is mainly secured through thermal power plants, with fuels available in the energy market (Energy Facts Norway 2018).

One special feature of the Norwegian hydropower system is its high storage capacity. Total storage capacity corresponds to 70% of annual Norwegian electricity consumption. The Northern country has half of Europe’s reservoir storage capacity, and more than 75% of Norwegian production capacity is flexible. Production can be rapidly increased and decreased as needed, at low cost. This is essential because there must be balance between production and consumption at all times in the power system. Also, the growing share of intermittent production technologies, such as wind and solar, makes it even more vital that there is flexibility available in the rest of the system.

- Electricity Price

The variable costs of hydropower production are low, since water, the actual energy source, is free. An owner of a run-of-river power plant will therefore be willing to generate electricity even if the prices is only just above zero. The same principle applies to intermittent production technologies such as wind and solar power. Intermittent production is generally independent of price, but varies with weather conditions.

On one hand, thermal power production, for example at coal-fired, gas-fired and nuclear power plants, is profitable provided that the electricity price covers the production costs at the time of production. These depend to a large degree on the prices of coal, gas and $CO_2$ emission allowances. On the other hand, hydropower producers who can store water will assess the situation differently. They constantly need to consider whether to produce electricity immediately, or to retain the water in reservoirs. It is the difference between the current and the expected electricity price that determines whether it is profitable to store water for short or longer periods.

It is challenging to manage storage reservoirs, because it is impossible to be sure how inflow will vary in future or how market conditions will develop. Reservoir management therefore requires considerable local knowledge and the ability to interpret changing, complex and uncertain information on inflow, consumption and market developments (Energy Facts Norway 2018).

Recently, a Norwegian newspaper reports about the highest level of power prices in 13 months due to the unexpected cold weather. “A kilowatt time now costs 0.402 kroner in southern Norway and 0.432 kroner in central and northern Norway. This is more than double the price in 2016, and an increase of between 50 and 83% over last year” (Norway Today 2018).

Therefore, it is evident how crucial the weather is for the Norwegian electricity market and how hardly is for the exact electricity price to be forecasted.

- Transport

The Norwegian government proposes in its budget proposal for 2018 to allocate 67.5 billion kroner to the transport budget, which is an increase of nearly 6.5% compared to the final budget for 2017. “This government has had an historic focus on transport. Never before has the focus been so high, with the simultaneous construction of new and modern infrastructure. Allocations since 2013 have increased by more than 60%, including the proposal for the 2018 budget” (The National Budget for 2018 2017).

Moreover, the government of Norway is focused on delivering better and safer roads nationwide, and it is the road network that will receive the largest budget increase in 2018. There is a strong contribution to more efficient and effective road construction, as well as an implementation of vital measures and initiatives designed to improve the exploitation of resources in the sector. According to the National Budget plan, the government proposes the allocation of about 2.5 billion kroner for measure and initiatives in the larger cities, an increase of 23% compared to the final budget of 2017. The funds will be used for incentive schemes for improvements in public transport, improvements to national highways, as well as for incentives and grants to major projects in public transport under urban environment agreements and urban growth agreements (The National Budget for 2018 2017).

The digital infrastructure is also a target for the Norwegian transport sector due to both trade & industry and critical social functions, which are becoming dependent on electronic communications and ITC systems. “New technology will also contribute to that we achieve our objectives as laid down in our transport policy”. Pilot-T, a grant arrangement established by the government with the idea to contribute to that new solutions. This project aims to provide the transport sector with new quick solutions, and also to prepare the ground so that Norwegian participants can compete in supplying new mobility solutions to the sector (CIA 2018a; The National Budget for 2018 2017).

- Policy Description

Norway is a global forerunner in the field of electromobility and the BEV market share is far higher than in any other country (Bjerkan, Nørbech, and Nordtømme 2016). The

Norwegian government's efforts in this area are driven by a desire to improve air quality, to drive up the use of renewable electricity and to reduce GHG (ABREVIATION) from the transport sector. In 1991, Norway is the first country in the world to implement a $CO_2$ tax on petroleum production. Moreover, successive policy interventions to impose greater costs on the environmental "externalities" of economic activities are framed as a means to neutralize the country's carbon footprint, which is particularly effective given the population's awareness of Norway's substantial exports on fossil fuels. Overall, environmental policies are presented to the public as not inherently conflicting with economic growth, which ensures that they are met with broadly approval despite the skepticism from energy-intensive industries (Berggren and Magnusson 2012).

Therefore, due to the strategic ambition for the country to be carbon-neutral by 2050, Norway has become a worldwide leader when it comes to use of BEVs. Seventy thousand BEVs are registered in Norway, accounting for approximately 18% of new car sales in 2015 (Rathjens et al. 2014). This BEV market share is far higher than in any other country of the globe. One undisputable reason for this relatively high market penetration are the strong incentives for promoting purchase and ownership of BEVs. Due to a comprehensive incentive package for BEVs the purchase price for a BEV is more or less equal to the price of a comparable ICEV. On the top of the purchase price incentives there are also incentives making the EV more convenient and cost-efficient in daily use (Figenbaum, Assum, and Kolbenstvedt 2015).

Figure 1 shows how formidable the growth rate of BEVs in Norway is the last few years. It pictures the cumulated number of registered EVs in Norway between 2009 and the first quarter of 2015. The figure shows that from a total BEV and PHEV fleet of barely 10.000 registered vehicles in 2012, the number rises to more than 50.000 BEVs and PHEVs in 2015. This brings the Norwegian passenger car fleet to nearly 2%.

*K.Y. Bjerkan et al. / Transportation Research Part D 43 (2016) 169–180*

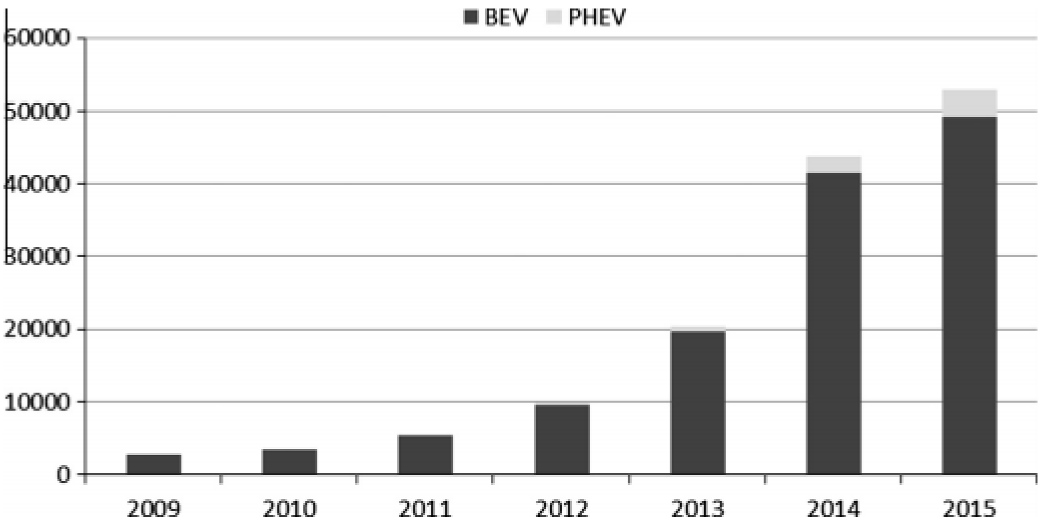


**Fig. 1.** Number of registered BEVs and PHEVs in Norway 2009–2015 (Q1).

Going back in the past, Norwegian consumers benefit from strong incentives for EV adoption since the mid-90s, most of them directed toward BEVs (Bjerkan, Nørbech, and Nordtømme 2016). As Norway, along with Denmark, has the highest purchase taxes on new cars in the world, heavy financial benefits bring the purchase cost of a BEV to the same level as a comparable ICEV.

Firstly, BEVs and hydrogen cars are exempted from vehicle registration tax, which involves considerable savings. Hybrids are not included in the taxation scheme, but as the tax is based on engine power as well as $CO_2$ and NOx emissions the total value remains low also for these vehicles.

Secondly, BEVs are excluded from value added tax (VAT), which in Norway currently is at 25%. These two exemptions have a significant effect on EV purchase cost. Table 2 gives a few examples of purchase costs in 2014 when buying a specific EV model compared to comparable ICE model.

Thirdly, BEVs and hydrogen cars pay the lowest rate of the vehicle license fee. This implicates lower savings than from the other tax incentives, but they are in return repetitive.

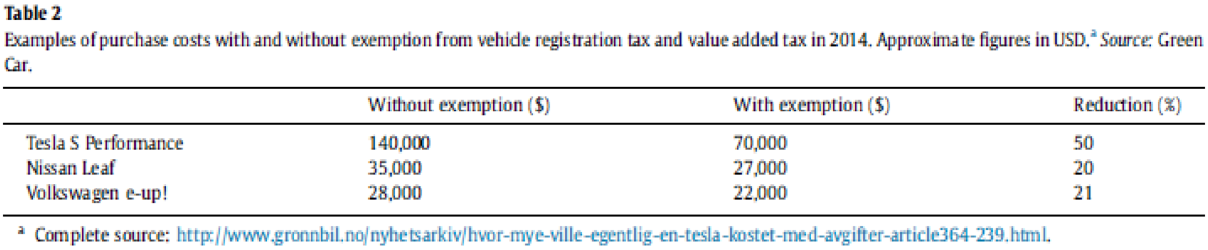


**Table 2**

Examples of purchase costs with and without exemption from vehicle registration tax and value added tax in 2014. Approximate figures in USD.[a] *Source:* Green Car.

| | Without exemption ($) | With exemption ($) | Reduction (%) |
|---|---|---|---|
| Tesla S Performance | 140,000 | 70,000 | 50 |
| Nissan Leaf | 35,000 | 27,000 | 20 |
| Volkswagen e-up! | 28,000 | 22,000 | 21 |

[a] Complete source: http://www.gronnbil.no/nyhetsarkiv/hvor-mye-ville-egentlig-en-tesla-kostet-med-avgifter-article364-239.html.

Other financial incentives for BEVs in Norway include exemption from road tolling and from paying ticket fees on ferries in most countries, and free parking on municipal public parking for BEVs and hydrogen cars alike. Regarding road tolling, Norwegian case compared to many other countries is not very special. This could be made revenue neutral by increasing prices for ICE vehicles in stages reflecting past lost revenue from the free passage of EVs. The same principle applies to free parking and ferry passage, though the latter rarely is relevant in the day-to-day mobility of citizens outside of Norway.

And finally, BEVs have access to bus lanes. Regarding bus lane access, this is “free incentive” that can be applied as part of a market introduction package in smaller and medium size cities wherever until the number of EVs reaches a level where it becomes a serious obstacle for public transport.

In general, all the policies taken imply that generous economic incentives can overcome diffusion barriers – such as anxieties related to vehicle range, charger availability and overall convenience – at least in the early period of technological uptake.

A study investigating the role of the incentives in promoting BEV ownership in Norway presents its results based on a member survey of the Norwegian EV association. An invitation sent to 11.000 members in June 2014, from which 3405 reply, giving a response rate of 31%. The respondents correspond to 12% of the EV owners in Norway at that time. The sample mostly includes owners of BEVs (99.5%), and given the characteristics of Norwegian incentives HEV owners (0.5%) are omitted from the analyses.

Moreover, considering the sharp increase in BEV purchases the last few years, the overall age of the Norwegian BEV fleet is relatively low. A total of 60% of BEV owners have purchased their BEV within the last year, and a cumulated 75% within the last two years. The results of the study show that the EV sample is dominated by men, age group 36-55 years, persons with college/university degree, high personal income and living in the capital area where the pressure on the transport system is particularly large. This study investigates the role of 7 different incentives – exemption from purchase tax, exemption from VAT, vehicle license fee reduction, exemption from road tolling, free parking, bus lane access and free ferry tickets. Although recognized as very essential, the charging infrastructure is not included here. The reason is that a majority of Norwegians (approximately 73%) live in row houses, family homes, detached and semi-detached houses (Norway 2013), where there is in-house opportunity for charging EVs. As such, public infrastructure for normal charging is less crucial than in many other countries. Fast charging might be more relevant, but is not included in the data (Mersky et al. 2016).

Additional, with Norway as the exception from other countries, EVs become more affordable than ICEVs. In this regard, the Norwegian case might be different, where income is less prominent predictor, which probably results from the competitive price of BEVs in the Norwegian market (Mersky et al. 2016).

Furthermore, the figure below shows how the respondents of the study rate the importance for buying a BEV (diamonds) and what percentage of the participants state that purchasing a BEV depends on a specific incentive (columns). Although the figure show that there are small differences in the respondents' rating of incentives, the role of different incentives is more of importance when considering which incentives are more essential for purchasing a BEV.

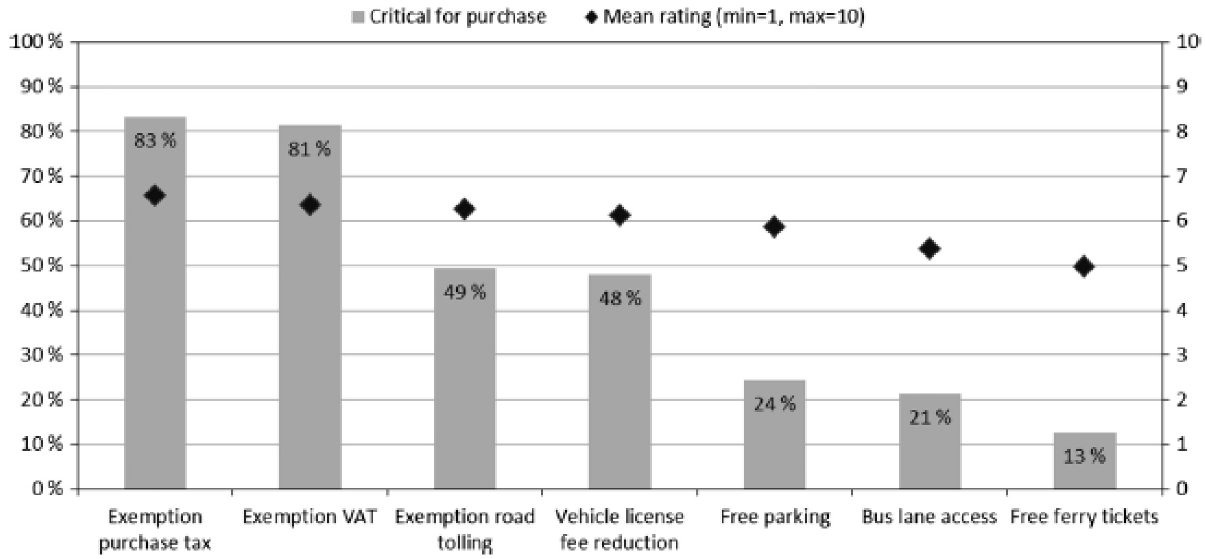


**Fig. 2.** Role of incentives for BEV purchase (*N* = 3384).

It is evident from the figure, that for more than 80% of the respondents' exemptions from purchase tax and VAT are crucial, which proves the suggestion that up-front price reduction is more effective incentive in promoting EV adoption. Also, there could be seen from the graph that exemption from road tolling and reducing the vehicle license are decisive to half of the sample, whereas the remaining incentives are critical for more particular groups (Mersky et al. 2016).

Further, despite the fact that exemption from purchase tax still dominates, exemption from road tolling and bus lane access are to a significant number of BEV owners the only decisive factor. Considering the marginal role of these incentives in other groups, they are not effective in broad recruitment of BEV users but could very well be the top of the scale for potential BEV buyers not perceptive to normally critical economic incentives. For example, residents in the third-most populous city in Norway, Trondheim, where road tolling is extensive, are especially prone to incentives which reduce use costs. In 2014, 16 additional road tolling stations in the city are established and according to statistics from the Green Car project the BEV fleet in Trondheim more than doubles (from 924 BEVs to 2065) from the year before. Therefore, as strong increase of BEV purchases is seen in the same year, the combination of extensive road tolling and exemptions for BEVs proves to be quite effective in promoting BEV adoption (Bjerkan, Nørbech, and Nordtømme 2016).

To sum up, Norway's most generous and long-running incentive structure for battery electric vehicles (BEVs) enables dramatic growth in electromobility over the last few years.

The removal of VAT rates, registration fees and annual motor taxes progressively encourage uptake. Other incentives to purchase BEVs are implemented, such as access to bus lanes, free parking and tolls, and reduced ferry charges. Despite the surge in growth, however, less than 3% of the total car fleet is electric, while the remainder is split between petrol and diesel vehicles.

### 4.2 Portugal

Figures from Portugal's tax authority (AT) reveal that for 2017 the electric vehicles in the country are 4.134 including mopeds, light passenger vehicles, heavy vehicles, motorcycles, tricycles and quads. Since Mobi.e, the company that manages the country's network of charging points as part of a state-sponsored pilot project, is initiated in 2009 as part of a state-sponsored pilot project, it is expected that number to rise to around 5.000 vehicles to the end of 2018, given the models coming onto the market and making it more attractive. During this year 14 fast-charging stations are to be installed in various cities and on five main motorways. Charging points are also to be set up in all the country's municipalities, so that by the end of the year there are to be 1.700 regular charging points and 50 fast-charging ones overseen by Mobi.e. Also, other stations are expected to be installed by private companies (TPN/Lusa 2017).

In particular, according to the most recent figures from EV Obsession and Clean Technica the growth of electric vehicles is fairly strong in Portugal (Ayre 2016). In this regard, first, the profile of Portugal will be observed in order to get a deeper look into the EV's policies taken in the country.

- Country's Profile

Portugal, officially the Portuguese Republic is a sovereign state in Western Europe, it comprises of the continental part of Portugal on the western coast of the Iberian Peninsula and the small archipelagos of Madeira and the Azores in the Atlantic Ocean. The most western European state is only bordered by one other country: Spain, in north and north east. Portugal shares a maritime border with Morocco.

Portugal covers an area of 92.090 km2, which makes the country the 112th country in the world. Population of Portugal is around 10.3 million people, with capital and largest city Lisbon (nearly 550.000 inhabitants) and official language Portuguese.

Portugal is a republic with a semi-presidential representative democracy, in which the chief of the state and commander in chief of the armed forces is the president, and the head of government is the prime minister, who is appointed by the president. The country has a multi-party system, in which members of the Portuguese Assembly are elected through a closed-list proportional representation system (World 2015; CIA 2018b).

- Economy

Since joining the European Community in 1986 Portugal becomes a diversified and increasingly service-based economy. Over the following two decades, successive governments privatize many state-controlled firms and privatize key areas of the economy, including the financial and telecommunications sectors. The country joins the Economic and Monetary Union in 1999 and along with 11 other EU members begins circulating the euro in 2002 (CIA 2018b).

The economy grows by more than the EU average for much of the 1990s, but the rate of growth slows in the period between 2001 and 2008. After the Global financial crisis in 2008, Portugal's economy contracts in 2009 and falls into recession from 2011 to 2013, as the government implements spending cuts and tax increases to comply with conditions of an EU-IMF financial rescue package, signed in May 2011. After successful exit of its EU-IMF program in May 2014, Portugal's economic recovery gains traction in 2015 due to strong exports and a rebound in private consumption. GDP growth accelerates in 2016, and reaches nearly 2.5% in 2017.

Recent data regarding Portugal's economy points to a heathy, but relatively slower, pace of economic expansion. Slower export growth in May against the backdrop of escalating global trade tensions is likely a factor in the drop in industrial production. Business sentiment climbs throughout the first quarter of 2017, thanks to a more favorable outlook on the construction and public works, and service sectors. Moreover, growth continues to be supported by the ongoing the housing boom. House prices increase more than 12% from a year before.

Another year of healthy economic surge is expected in 2018, thanks to higher foreign investment, the flourishing tourism and resilient private consumption supported by strong job creation, anticipated to lift wages. A greater inflow of foreign investment is also expected to continue driving the housing boom. Nevertheless, growth is expected to moderate from the previous year, owing to an anticipated slowdown in domestic demand. In general, economists expect the economy to grow by 2.2% in 2018 (Economics 2018).

Regarding the labor force, employment in Portugal is fairly diversified. More than half of all workers are employed in services, while one-eighth work in the primary sector, including agriculture and mining. Manufacturing, construction, and the public utilities employ one-quarter of workers.

However, although unemployment improves steadily since peaking at 18% in 2013, it still remains high, at 9.7% in 2017 (The World Bank 2018b).

- Electricity and Electricity Prices

Portugal imports about four-fifths of its energy supplies and depends heavily on the importation of petroleum and petroleum products as well as coal, which accounts for nearly 25% of the country's electricity production. A natural gas pipeline from North Africa is completed in 1997. Nearly one-fifth of Portugal's electricity is provided by hydropower, and a smaller proportion comes from thermal energy (CIA 2018b).

In the beginning of 21st century, Portugal increases immensely its use of alternative energy sources. A large wind farm – largest in Europe at the time is opened in 2008 in northern Portugal, and one of the world's largest photovoltaic farms, which use solar panels to generate electricity. Furthermore, the British newspaper "Independent" reports that in March 2018 for the first time in the last 40 years Portugal generates more renewable energy than it needs (Smith 2018). According to data from the country's power grid operator REN, energy from renewable sources makes up 103.6% of mainland electricity consumption, even though fossil fuels are used to occasionally top up the electricity supply. A report by the Portuguese Renewable Energy Association and the sustainability group ZERO claims that that record is an example of what the future holds for renewable energy. Weather conditions in the country also help production from renewable sources, as wet and windy weather imply output from hydroelectric dams and wind turbines is high (Smith 2018).

Moreover, the local renewable association APREN highlights how the higher penetration of renewables is contributing to significantly lower power prices on the electricity market. According to the association, average power prices on the daily market drops around 10%, from 43.94EUR/MWh in March 2016, to 39.75 EUR/MWh in March 2018. Therefore, it is expected that by 2040 the production of renewable electricity would be able to guarantee, in a cost-effective way, the total annual electricity consumption of mainland Portugal (Bellini 2018).

- Transport

For much of the 20th century transport and communications are seriously neglected in Portugal, but the massive funding from the EU remedy the situation. As a result the total road network is extended, a four-lane superhighway connects Lisbon with the northern capital Porto. Also, expressways reach the largest towns and extend to the border and ports as well as secondary roads link the towns with almost every part of the interior (World 2015).

Moreover, easy access to credit and a massive investment to improve the road infrastructure leads Portugal from a car ratio of 258 cars per thousand inhabitants in 1990 to over 500 in 2013, with the distance per capita travelled also increasing to 10.000 km per year. In Portugal, the increase of mobility, combined with the increase of prices, leads to an increase in what is spent on fossil fuels from 1320 million Euros in 1998 to 6232 million in 2013. Tolls are introduced in the road networks, as well as paid parking in many cities, leading to an increase in the average monthly cost of transportation to about 370 Euros per automobile (Delgado et al. 2018).

Another essential trend for the mobility in Portugal is the increasing of Renewable Energy Sources (RES) for electricity generation and the improvements achieved in energy storage technologies, which has led to increasing interest in Electric Vehicles (Lorf et al. 2013). Furthermore, pure EVs, including BEVs, and PHEVs are progressively seen as attractive solutions, which lead to the decarbonization of the energy economy and a shift to the use of renewable energy sources. EVs are able to address mobility needs and take advantage of the endogenous renewable energy captured with increasingly competitive technologies, with special focus on wind and solar power generation, thus contributing to greater energy independence.

Accordingly, the increase in renewable generation capacity in Portugal leads to a gradual decarbonization of the Portuguese electricity mix, with 55.6% of the generation in 2016 ensured by RES, 27.6% of which is generated by hydropower and 21.8% by wind power (Delgado et al. 2018). Therefore, the low carbon content of the electricity generated ensures a low environmental impact associated with the use of EVs (Faria et al. 2012). At the same time, EVs can be a major solution to avoiding the generation surplus due to intermittent generation in the Portuguese electrical grid, since charging of EVs can be coordinated to use such surpluses.

Another positive aspect of this evolution is the progressive reduction of the environmental impact of the transportation sector in Portugal (Camus, Farias, and Esteves 2011). The $CO_2$ emissions for a traditional vehicle are close to 150 $gCO_2$ /km, which leads to 2500 $kgCO_2$ /year for vehicles traveling 15.000 km. For a PEV, which operates 75% of the time in electric mode, considering 122 $gCO_2$ /kW h the average emission for the Portuguese electricity mix, average emissions are reduced to approximately 587 $kgCO_2$ /year. Table 8 depicts the average energy consumption and emission reductions for the penetration ratio of PEVs considered. The emissions decrease varies between 165.400 ton/$CO_2$ for 100 thousand vehicles and 1.654.000 ton/$CO_2$ for one million vehicles.

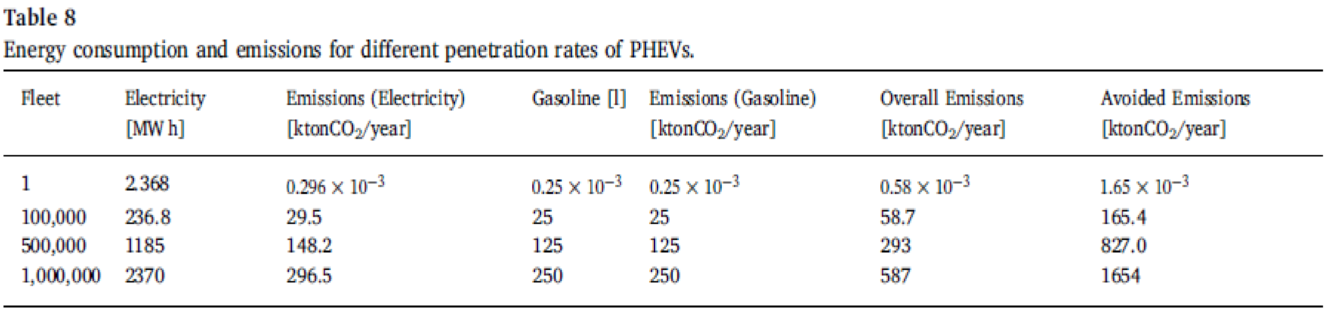


**Table 8**
Energy consumption and emissions for different penetration rates of PHEVs.

| Fleet | Electricity [MW h] | Emissions (Electricity) [kton$CO_2$/year] | Gasoline [l] | Emissions (Gasoline) [kton$CO_2$/year] | Overall Emissions [kton$CO_2$/year] | Avoided Emissions [kton$CO_2$/year] |
|---|---|---|---|---|---|---|
| 1 | 2.368 | $0.296 \times 10^{-3}$ | $0.25 \times 10^{-3}$ | $0.25 \times 10^{-3}$ | $0.58 \times 10^{-3}$ | $1.65 \times 10^{-3}$ |
| 100,000 | 236.8 | 29.5 | 25 | 25 | 58.7 | 165.4 |
| 500,000 | 1185 | 148.2 | 125 | 125 | 293 | 827.0 |
| 1,000,000 | 2370 | 296.5 | 250 | 250 | 587 | 1654 |

Moreover, there is a study carried out in Portugal between 2011 and 2013, over a 36-month period, which reveals that the Portuguese travel on average nearly 25 km on a daily basis. Further, the study shows that 14% of the targeted 4.329 users of BEVs drive less than 25 km per day, 64% less than 50 km, 92% less than 75 km and only 8% drive over 75 km daily (Faria et al. 2012). Therefore, this data proves that considering the autonomy provided by current PEVs, these vehicles already offer consistent answers for the mobility needs of most citizens. Furthermore, Portugal invests to a great extent in recharge infrastructure and there is currently (July 2017) a fleet of 5.260 EVs circulating with ambitious targets to expand this fleet (International Energy Agency 2017b).

- Policy Description

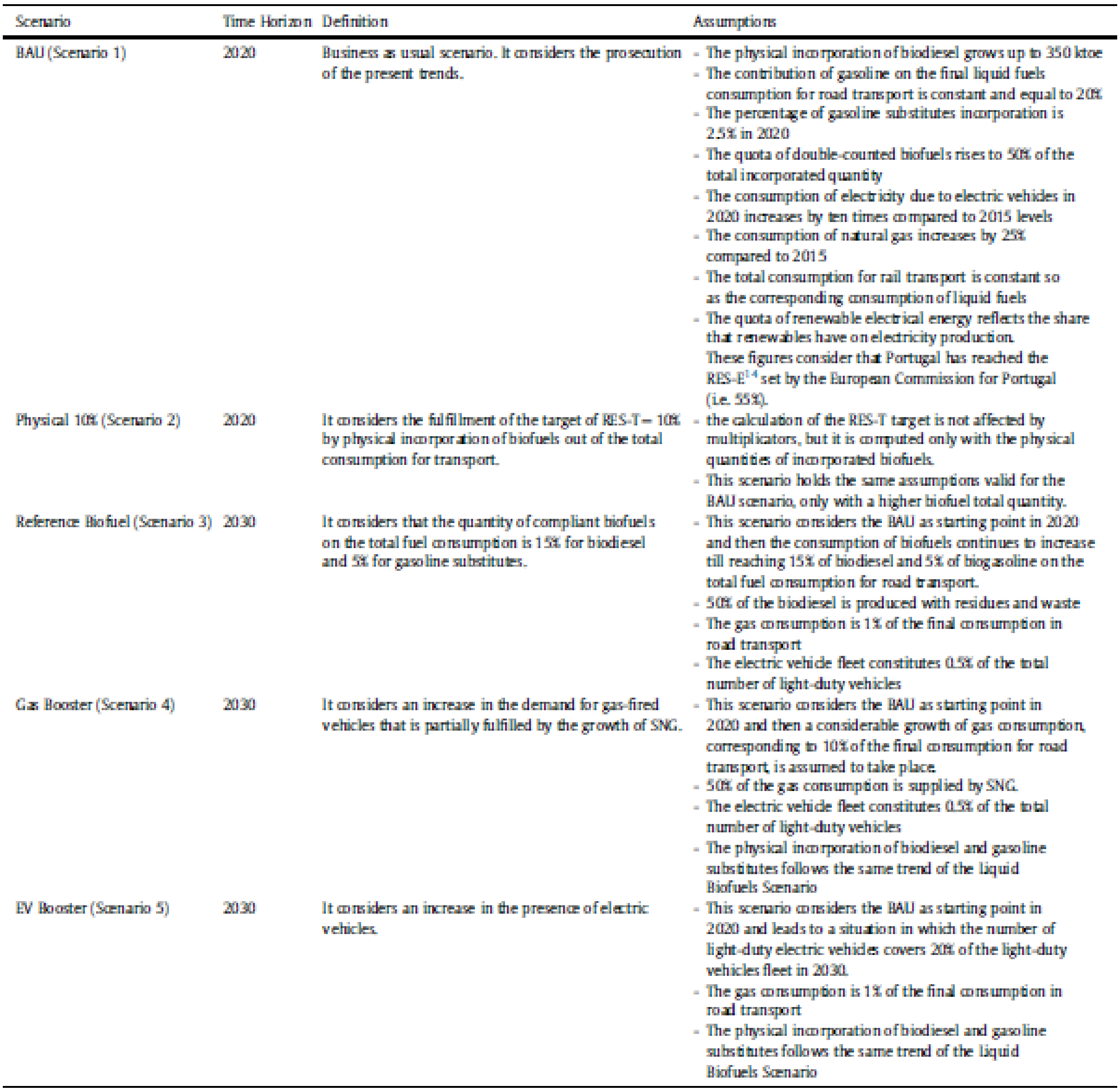
The need for energy efficiency improvements in the transport sector and the tightening of vehicle emission standards favor the emergence of alternative vehicle technologies, especially through the electrification of the transport sector. The higher energy efficiency of electric vehicles, the elimination of local pollutants emissions and the possibility to use renewable electricity are the major factors in favor of the introduction of this alternative. Therefore, with increasing governmental support for electric mobility it is likely that the EVs will be considered as one of the most effective way of resolving some issues affecting the road transport

In Portugal, in contrast to an early investment in a national recharging stations network, the adoption of EV is slow, with a 0.4% share in sales in 2015 and 2016 (International Energy Agency 2017b). In order to promote the recourse to environmentally friendly mobility solutions, the Portuguese government establishes a set of incentives to increase the share of renewables in the consumption of several types of means of transport (Lorenzi and Baptista 2018).

The supporting scheme is reformed in 2015 after the introduction of an end-of-life dismantling incentive, which implies a delivery of an old vehicle in exchange for a newly registered electric vehicle. The contribution is equal to 4.500 € for battery electric vehicles and 2.250 € for plug-in electric vehicles. Nevertheless, these values halve in 2016 and then again in 2017. Other benefits include registration, ownership tax benefits, local benefits such as free parking (e.g. in the city of Lisbon), and discount on electricity bills. In comparison, the above mentioned benefits are lower than those available in some European countries that are strongly promoting electric mobility (EAFO 2017b). For instance, as previously discussed, Norway offers the total exemption of the purchase tax and VAT. However, the presence of a purchase bonus in Portugal denotes the willingness to favor the internal market.

Moreover, in order to assess the future trends of RES (renewable energy sources) incorporation in the Portuguese transport sector, the evolution of the total energy consumption for transport is determined (Lorenzi and Baptista 2018). The analysis of the RES presence in Portugal is performed through the assessment of different scenarios which depict possible trajectories of the transport sector in several directions, as presented in Table 8.

**Table 8**
Definition of the scenarios and corresponding assumptions.



| Scenario | Time Horizon | Definition | Assumptions |
|---|---|---|---|
| BAU (Scenario 1) | 2020 | Business as usual scenario. It considers the prosecution of the present trends. | - The physical incorporation of biodiesel grows up to 350 ktoe<br>- The contribution of gasoline on the final liquid fuels consumption for road transport is constant and equal to 20%<br>- The percentage of gasoline substitutes incorporation is 2.5% in 2020<br>- The quota of double-counted biofuels rises to 50% of the total incorporated quantity<br>- The consumption of electricity due to electric vehicles in 2020 increases by ten times compared to 2015 levels<br>- The consumption of natural gas increases by 25% compared to 2015<br>- The total consumption for rail transport is constant so as the corresponding consumption of liquid fuels<br>- The quota of renewable electrical energy reflects the share that renewables have on electricity production.<br>These figures consider that Portugal has reached the RES-E[14] set by the European Commission for Portugal (i.e. 55%). |
| Physical 10% (Scenario 2) | 2020 | It considers the fulfillment of the target of RES-T = 10% by physical incorporation of biofuels out of the total consumption for transport. | - the calculation of the RES-T target is not affected by multiplicators, but it is computed only with the physical quantities of incorporated biofuels.<br>- This scenario holds the same assumptions valid for the BAU scenario, only with a higher biofuel total quantity. |
| Reference Biofuel (Scenario 3) | 2030 | It considers that the quantity of compliant biofuels on the total fuel consumption is 15% for biodiesel and 5% for gasoline substitutes. | - This scenario considers the BAU as starting point in 2020 and then the consumption of biofuels continues to increase till reaching 15% of biodiesel and 5% of biogasoline on the total fuel consumption for road transport.<br>- 50% of the biodiesel is produced with residues and waste<br>- The gas consumption is 1% of the final consumption in road transport<br>- The electric vehicle fleet constitutes 0.5% of the total number of light-duty vehicles |
| Gas Booster (Scenario 4) | 2030 | It considers an increase in the demand for gas-fired vehicles that is partially fulfilled by the growth of SNG. | - This scenario considers the BAU as starting point in 2020 and then a considerable growth of gas consumption, corresponding to 10% of the final consumption for road transport, is assumed to take place.<br>- 50% of the gas consumption is supplied by SNG.<br>- The electric vehicle fleet constitutes 0.5% of the total number of light-duty vehicles<br>- The physical incorporation of biodiesel and gasoline substitutes follows the same trend of the Liquid Biofuels Scenario |
| EV Booster (Scenario 5) | 2030 | It considers an increase in the presence of electric vehicles. | - This scenario considers the BAU as starting point in 2020 and leads to a situation in which the number of light-duty electric vehicles covers 20% of the light-duty vehicles fleet in 2030.<br>- The gas consumption is 1% of the final consumption in road transport<br>- The physical incorporation of biodiesel and gasoline substitutes follows the same trend of the Liquid Biofuels Scenario |

Scenarios 1 and 2 are near-term scenarios with the objective to highlight the distortion in the accounting of GHG emissions reduction, in order to quantify if the achieved results are satisfactory. On the contrary, Scenarios 3, 4 and 5 continue until 2030 (medium-term scenarios) and represent the situation of the Portuguese transport sector for the cases in which the only pathway toward fossil fuel substitution is the incorporation of liquid biofuels, or alternative vehicle technologies (i.e. electric vehicles and gas-fired) reach much bigger market shares.

In this regard, Portugal plans to boost its electric mobility and assumes that by 2030 20% of its light-duty vehicles fleet will be constituted by electric vehicles, resulting in 1.24 million electric vehicles. That number corresponds to 4.5% of the total road transport consumption. The objective of a 20% share of the LDV fleet is definitely ambitious, however, this aim represents the expansion potential of the EVs in the next 15 years. Furthermore, the main impact of such a large electric vehicle share on the electricity generation would increase the total electricity demand of the country with nearly 2.5 TWh (5% of the current consumption values) (REN 2016). This would possibly entail that even more investments in renewable plants would be necessary to keep a high renewable content in the electricity generation. Moreover, the electricity consumed in road transport is supposed to reflect the composition of the national energy mix in terms of $CO_2$ emissions, unless very strong incentives are implemented to force the electric vehicles to be charged in specific time slots.

# 5 Conclusion

Electric vehicles can have several positive impacts on the economy, environment and electrical system operation. In this regard policy incentives, which are meant to increase the attractiveness of light duty electric vehicles, prove to be an effective way to obtain an increase of EV's market share in Europe. Moreover, this work focused on the distinct impacts, which the policy measures have, taken to incentivize EV's adoption. The comparison between the two European countries, Norway and Portugal, at the end of this thesis, intended to show the different BEV development stages of both countries and how in practice policy stimulus support the EV market growth.

However, existing policy mechanisms that aim to thrust PEVs immediately into the mass market, demonstrate a "mainstream market bias" and prove to be inefficient, costly, and ineffective. Instead, policy makers aiming to give BEVs a foothold in the market should also focus on niche markets and green consumers, and more specifically on carsharing users. So far, two arguments can be made in support of eliminating the mainstream market bias of current policies toward a policy of cultivating niche markets. The first is efficiency. Policy incentives featuring a mainstream market bias have proven to be inefficient and costly. The second is effectiveness due to the fact that it brings to proof, that using such approaches as strategic niche management, accessible loans and financing, and appropriately targeted stimulus, would be more effective in achieving potential societal benefits.

Further, it has been shown that most of the existing literature overlooks the possibility of there being different groups of early adopters. Results from this work reveal two distinct groups, which are referred as low-end adopters and high-end adopters. These two groups have substantial differences in their socio-economic profiles, with high-end adopters being of higher income, education and age. Also, it has been identified, that high-end adopters have greater empathy and it takes them less time to adopt a new technology. In addition to this, the different future purchase intentions of BEV owners also add to the evidence that both groups of adopters are not homogenous.

Nevertheless, policy incentives being taken are meant to be in place as long as the electric vehicle market is not able to function on its own. In case many people switch to EVs, it is not viable to keep on giving access to bus lanes or to provide free parking. Conversely, if governments provide use-benefits, so then those policy incentives should be consistent over time in order to be credible and effective.

Also, most of the initial EV buyers obtain vehicles through financing rather than paying the full price upfront, so that many of them would face financial barriers, which would be either the ability to pay, or the willingness to pay for BEV. Those potential early adopters are more likely to be aware of BEV fuel savings or environmental benefits. However, the ability to pay could be hindered by the financing process. Even if potential buyers realize that fuel savings would bring monthly BEV ownership costs to an affordable level, many might not qualify for a loan, as fewer people will qualify for the higher loans associated with BEVs' greater upfront capital costs.

Therefore, for the governments, who aim to grow their electric vehicle market share, it is essential to target the potential early adopters not as a homogeneous group, but to make a distinction between those, who might be more interested in the use-benefits of a BEV (Portugal), and those who would adopt the "green" vehicle, if only there are substantial abatements due to the higher initial investment costs (Norway).

In summary it can be said that living in a culture where replacement is king, we could take value from that and replace an old and environmental unfriendly technology in a way that hurts less our planet. Routinely, we did put the car in the center of our daily activities, so that it is essential to us to rethink the way we are using it. As individual consumers, one main thing we could do for the environment is to decrease the environmental impact of our vehicles, and to avoid the extra carbon dioxide emissions.

# Bibliography

Administration, US Energy Information. 2018. “Short-Term Energy Outlook.” 2018. https://www.eia.gov/outlooks/steo/.

Al-Alawi, Baha M., and Thomas H. Bradley. 2013. “Total Cost of Ownership, Payback, and Consumer Preference Modeling of Plug-in Hybrid Electric Vehicles.” *Applied Energy* 103: 488–506. https://doi.org/10.1016/j.apenergy.2012.10.009.

Axsen, Jonn, and Kenneth S. Kurani. 2011. “Interpersonal Influence in the Early Plug-in Hybrid Market: Observing Social Interactions with an Exploratory Multi-Method Approach.” *Transportation Research Part D: Transport and Environment* 16 (2): 150–59. https://doi.org/10.1016/j.trd.2010.10.006.

Axsen, Jonn, Kenneth S. Kurani, and Andrew Burke. 2010. “Are Batteries Ready for Plug-in Hybrid Buyers?” *Transport Policy* 17 (3): 173–82. https://doi.org/10.1016/j.tranpol.2010.01.004.

Ayre, James. 2016. “500,000 ELECTRIC CARS NOW ON EUROPEAN ROADS.” 2016. https://evobsession.com/500000-electric-cars-now-european-roads-charts/.

Bakker, Sjoerd, and Jan Jacob Trip. 2013. “Policy Options to Support the Adoption of Electric Vehicles in the Urban Environment.” *Transportation Research Part D: Transport and Environment* 25. Elsevier Ltd: 18–23. https://doi.org/10.1016/j.trd.2013.07.005.

Bellini, Emiliano. 2018. “Portugal. Renewables Are Driving down Electricity Prices.” PV Magazine. 2018. https://www.pv-magazine.com/2018/04/12/portugal-renewables-are-driving-down-electricity-prices/.

Berggren, Christian, and Thomas Magnusson. 2012. “Reducing Automotive Emissions — The Potentials of Combustion Engine Technologies and the Power of Policy.” *Energy Policy* 41 (41): 636–43. https://doi.org/10.1016/j.enpol.2011.11.025.

Bjerkan, Kristin Ystmark, Tom E. Nørbech, and Marianne Elvsaas Nordtømme. 2016. “Incentives for Promoting Battery Electric Vehicle (BEV) Adoption in Norway.” *Transportation Research Part D: Transport and Environment* 43: 169–80. https://doi.org/10.1016/j.trd.2015.12.002.

Bonges, Henry A., and Anne C. Lusk. 2016. “Addressing Electric Vehicle (EV) Sales and Range Anxiety through Parking Layout, Policy and Regulation.” *Transportation Research Part A: Policy and Practice* 83: 63–73. https://doi.org/10.1016/j.tra.2015.09.011.

Brownstone, David, David S. Bunch, and Kenneth Train. 2000. “Joint Mixed Logit Models of Stated and Revealed Preferences for Alternative-Fuel Vehicles.” *Transportation Research Part B: Methodological* 34 (5): 315–38. https://doi.org/10.1016/S0191-2615(99)00031-4.

Bühler, Franziska, Peter Cocron, Isabel Neumann, Thomas Franke, and Josef F. Krems. 2014. “Is EV Experience Related to EV Acceptance? Results from a German Field Study.” *Transportation Research Part F: Traffic Psychology and Behaviour* 25 (PART A): 34–49. https://doi.org/10.1016/j.trf.2014.05.002.

Campbell, Amy R., Tim Ryley, and Rob Thring. 2012. “Identifying the Early Adopters of Alternative Fuel Vehicles: A Case Study of Birmingham, United Kingdom.” *Transportation Research Part A: Policy and Practice* 46 (8): 1318–27. https://doi.org/10.1016/j.tra.2012.05.004.

Camus, C., T. Farias, and J. Esteves. 2011. “Potential Impacts Assessment of Plug-in Electric Vehicles on the Portuguese Energy Market.” *Energy Policy* 39 (10): 5883–97. https://doi.org/10.1016/j.enpol.2011.06.042.

CIA. 2018a. “Norway.” The World Factbook. 2018. https://www.cia.gov/library/publications/the-world-factbook/geos/no.html.

———. 2018b. “Portugal.” The World Factbook. 2018. https://www.cia.gov/library/publications/resources/the-world-factbook/geos/po.html.

Database, The EV Sales. 2017. “EV Sales.” EV-Volumes. 2017. http://www.ev-volumes.com.

Delgado, Joaquim, Ricardo Faria, Pedro Moura, and Aníbal T. de Almeida. 2018. “Impacts of Plug-in Electric Vehicles in the Portuguese Electrical Grid.” *Transportation Research Part D: Transport and Environment* 62: 372–85. https://doi.org/10.1016/j.trd.2018.03.005.

Diamond, David. 2009. “The Impact of Government Incentives for Hybrid-Electric Vehicles: Evidence from US States.” *Energy Policy* 37 (3): 972–83.

https://doi.org/10.1016/j.enpol.2008.09.094.

Dijk, Marc, Renato J. Orsato, and René Kemp. 2013. “The Emergence of an Electric Mobility Trajectory.” *Energy Policy* 52: 135–45. https://doi.org/10.1016/j.enpol.2012.04.024.

EAFO. 2017a. “Charging Stations EU.” European Alternative Fuels Observatory. 2017. http://www.eafo.eu/eu.

———. 2017b. “Incentives Summary Portugal.” 2017. http://www.eafo.eu/content/portugal#country_pev_market_share_graph_anchor.

EC. 2013. “Clean Power for Transport: A European Alternative Fuels Strategy.” *European Commission*, 1–11.

Economics, Focus. 2018. “Portugal Economic Outlook.” 2018. https://www.focus-economics.com/countries/portugal.

Economist. 2017. “After Electric Cars, What More Will It Take for Batteries to Change the Face of Energy?” *Economist*, 2017.

Egbue, Ona, and Suzanna Long. 2012. “Barriers to Widespread Adoption of Electric Vehicles: An Analysis of Consumer Attitudes and Perceptions.” *Energy Policy* 48: 717–29. https://doi.org/10.1016/j.enpol.2012.06.009.

Energy Facts Norway. 2018. “Electricity Production.” 27th February. 2018. https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/.

Faria, Ricardo, Pedro Moura, Joaquim Delgado, and Anibal T. De Almeida. 2012. “A Sustainability Assessment of Electric Vehicles as a Personal Mobility System.” *Energy Conversion and Management* 61: 19–30. https://doi.org/10.1016/j.enconman.2012.02.023.

Figenbaum, Erik, Terje Assum, and Marika Kolbenstvedt. 2015. “Electromobility in Norway: Experiences and Opportunities.” *Research in Transportation Economics* 50: 29–38. https://doi.org/10.1016/j.retrec.2015.06.004.

Fulton, Lew, Pierpaolo Cazzola, and François Cuenot. 2009. “IEA Mobility Model (MoMo) and Its Use in the ETP 2008.” *Energy Policy* 37 (10): 3758–68. https://doi.org/10.1016/j.enpol.2009.07.065.

Gallagher, Kelly Sims, and Erich Muehlegger. 2011. “Giving Green to Get Green? Incentives and Consumer Adoption of Hybrid Vehicle Technology." *Journal of Environmental Economics and Management* 61 (1): 1–15. https://doi.org/10.1016/j.jeem.2010.05.004.

Gärling, Anita, and John Thøgersen. 2001. "Marketing of Electric Vehicles." *Business Strategy and the Environment* 10 (1): 53–65. https://doi.org/10.1002/1099-0836(200101/02)10:1<53::AID-BSE270>3.0.CO;2-E.

Genovese, Antonino, Fernando Ortenzi, and Carlo Villante. 2015. "On the Energy Efficiency of Quick DC Vehicle Battery Charging." *World Electric Vehicle Journal* 7 (4): 570–76.

Gnann, Till, and Patrick Plötz. 2015. "A Review of Combined Models for Market Diffusion of Alternative Fuel Vehicles and Their Refueling Infrastructure." *Renewable and Sustainable Energy Reviews* 47: 783–93. https://doi.org/10.1016/j.rser.2015.03.022.

Government.no. 2013. "Norway's Oil History." 2013. https://www.regjeringen.no/en/topics/energy/oil-and-gas/norways-oil-history-in-5-minutes/id440538/.

Green, Erin H., Steven J. Skerlos, and James J. Winebrake. 2014. "Increasing Electric Vehicle Policy Efficiency and Effectiveness by Reducing Mainstream Market Bias." *Energy Policy* 65. Elsevier: 562–66. https://doi.org/10.1016/j.enpol.2013.10.024.

Hall, Dale, Marissa Moultak, and Nic Lutsey. 2017. "Electric Vehicle Capitals of the World: Demonstrating the Path to Electric Drive [White Paper]." *The International Council on Clean Transportation*.

Hardman, Scott, Eric Shiu, and Robert Steinberger-Wilckens. 2016. "Comparing High-End and Low-End Early Adopters of Battery Electric Vehicles." *Transportation Research Part A: Policy and Practice* 88: 40–57. https://doi.org/10.1016/j.tra.2016.03.010.

Hawkins, Troy R., Bhawna Singh, Guillaume Majeau-Bettez, and Anders Hammer Strømman. 2013. "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles." *Journal of Industrial Ecology* 17 (1): 53–64. https://doi.org/10.1111/j.1530-9290.2012.00532.x.

Hidrue, Michael K., George R. Parsons, Willett Kempton, and Meryl P. Gardner. 2011. "Willingness to Pay for Electric Vehicles and Their Attributes." *Resource and Energy Economics* 33 (3): 686–705. https://doi.org/10.1016/j.reseneeco.2011.02.002.

ICCT. 2018. "Passenger Vehicle Fuel Economy." The International Council on Clean

Transportation. 2018. https://www.theicct.org/chart-library-passenger-vehicle-fuel-economy.

International Energy Agency. 2017a. *Global EV Outlook 2017: Two Million and Counting*. *IEA Publications*. https://doi.org/10.1787/9789264278882-en.

———. 2017b. “Global EV Outlook 2017: Two Million and Counting.” *IEA Publications,* 1–71. https://doi.org/10.1787/9789264278882-en.

IPEEC. 2017. “IPEEC Annual Report.” 2017. https://ipeec.org/newsroom/265-launch-of-ipeec-s-annual-report-2017.html.

Kemp, René, Johan Schot, and Remco Hoogma. 1998. “Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management.” *Technology Analysis & Strategic Management* 10 (2): 175–98. https://doi.org/10.1080/09537329808524310.

Kley, Fabian, Christian Lerch, and David Dallinger. 2011. “New Business Models for Electric Cars-A Holistic Approach.” *Energy Policy* 39 (6): 3392–3403. https://doi.org/10.1016/j.enpol.2011.03.036.

Kriston, Akos, Tamás Szabó, and György Inzelt. 2010. “The Marriage of Car Sharing and Hydrogen Economy: A Possible Solution to the Main Problems of Urban Living.” *International Journal of Hydrogen Energy* 35 (23): 12697–708. https://doi.org/10.1016/j.ijhydene.2010.08.110.

Krupa, Joseph S., Donna M. Rizzo, Margaret J. Eppstein, D. Brad Lanute, Diann E. Gaalema, Kiran Lakkaraju, and Christina E. Warrender. 2014. “Analysis of a Consumer Survey on Plug-in Hybrid Electric Vehicles.” *Transportation Research Part A: Policy and Practice* 64: 14–31. https://doi.org/10.1016/j.tra.2014.02.019.

Kurani, Kenneth S., Tom Turrentine, and Daniel Sperling. 1994. “Demand for Electric Vehicles in Hybrid Households: An Exploratory Analysis.” *Transport Policy* 1 (4): 244–56. https://doi.org/10.1016/0967-070X(94)90005-1.

Lane, Ben, and Stephen Potter. 2007. “The Adoption of Cleaner Vehicles in the UK: Exploring the Consumer Attitude-Action Gap.” *Journal of Cleaner Production* 15 (11–12): 1085–92. https://doi.org/10.1016/j.jclepro.2006.05.026.

Langbroek, Joram H.M., Joel P. Franklin, and Yusak O. Susilo. 2016. “The Effect of Policy

Incentives on Electric Vehicle Adoption." *Energy Policy* 94. Elsevier: 94–103. https://doi.org/10.1016/j.enpol.2016.03.050.

———. 2017. "Electric Vehicle Users and Their Travel Patterns in Greater Stockholm." *Transportation Research Part D: Transport and Environment* 52: 98–111. https://doi.org/10.1016/j.trd.2017.02.015.

Lesage, Dries, Thijs Van de Graaf, and Kirsten Westphal. 2010. "G8+5 Collaboration on Energy Efficiency and IPEEC: Shortcut to a Sustainable Future?" *Energy Policy* 38 (11): 6419–27. https://doi.org/10.1016/j.enpol.2009.09.043.

Lieven, Theo. 2015. "Policy Measures to Promote Electric Mobility - A Global Perspective." *Transportation Research Part A: Policy and Practice* 82: 78–93. https://doi.org/10.1016/j.tra.2015.09.008.

Lieven, Theo, Silke Mühlmeier, Sven Henkel, and Johann F. Waller. 2011. "Who Will Buy Electric Cars? An Empirical Study in Germany." *Transportation Research Part D: Transport and Environment* 16 (3): 236–43. https://doi.org/10.1016/j.trd.2010.12.001.

Lorenzi, Guido, and Patrícia Baptista. 2018. "Promotion of Renewable Energy Sources in the Portuguese Transport Sector: A Scenario Analysis." *Journal of Cleaner Production* 186: 918–32. https://doi.org/10.1016/j.jclepro.2018.03.057.

Lorf, Clemens, Ricardo F. Mart??nez-Botas, David A. Howey, Luca Lytton, and Ben Cussons. 2013. "Comparative Analysis of the Energy Consumption and CO2 Emissions of 40 Electric, Plug-in Hybrid Electric, Hybrid Electric and Internal Combustion Engine Vehicles." *Transportation Research Part D: Transport and Environment* 23: 12–19. https://doi.org/10.1016/j.trd.2013.03.004.

Luè, Alessandro, Alberto Colorni, Roberto Nocerino, and Valerio Paruscio. 2012. "Green Move: An Innovative Electric Vehicle-Sharing System." *Procedia - Social and Behavioral Sciences* 48: 2978–87. https://doi.org/10.1016/j.sbspro.2012.06.1265.

McKinsey. 2014. "EVolution; Electric Vehicles in Europe: Gearing up for a New Phase?" *Electric Vehicles in Europe*. https://doi.org/10.1016/j.retrec.2015.06.004.

Melaina, Marc, and Joel Bremson. 2008. "Refueling Availability for Alternative Fuel Vehicle Markets: Sufficient Urban Station Coverage." *Energy Policy* 36 (8): 3233–41. https://doi.org/10.1016/j.enpol.2008.04.025.

Mersky, Avi Chaim, Frances Sprei, Constantine Samaras, and Zhen Sean Qian. 2016. “Effectiveness of Incentives on Electric Vehicle Adoption in Norway.” *Transportation Research Part D: Transport and Environment* 46: 56–68. https://doi.org/10.1016/j.trd.2016.03.011.

Meyer, I., M. Leimbach, and C. C. Jaeger. 2007. “International Passenger Transport and Climate Change: A Sector Analysis in Car Demand and Associated CO2emissions from 2000 to 2050.” *Energy Policy* 35 (12): 6332–45. https://doi.org/10.1016/j.enpol.2007.07.025.

Min, Haitao, Dongjin Ye, and Yuanbin Yu. 2013. “Optimization of an Extended-Range Electric Vehicle.” In *Lecture Notes in Electrical Engineering*, 191 LNEE:275–85. https://doi.org/10.1007/978-3-642-33777-2_21.

Newbery, David, and Goran Strbac. 2016. “What Is Needed for Battery Electric Vehicles to Become Socially Cost Competitive?” *Economics of Transportation* 5: 1–11. https://doi.org/10.1016/j.ecotra.2015.09.002.

News, BBC. 2018. “Norway Country Profile.” 19 April. 2018. https://www.bbc.co.uk/news/world-europe-17743896.

Nissan Motor Co. 2012. “LEAF to Home Electricity Supply System with Nissan LEAF.” *LEAF to Home 2012.7.11 Nissan Motor Co., LTD.*

Norway, Statistics. 2013. “Domestic Transport Performances, 2012.” *Statbank*. http://ssb.no/en/transport-og-reiseliv/statistikker/transpinn%5Cnpapers2://publication/uuid/AB837D6C-9FF7-46FD-A205-BB21454F73EB.

Norway Today. 2018. “Surge in Electricity Prices.” *15th July*, 2018. http://norwaytoday.info/finance/surge-electricity-prices/.

Poullikkas, Andreas. 2015. “Sustainable Options for Electric Vehicle Technologies.” *Renewable and Sustainable Energy Reviews* 41: 1277–87. https://doi.org/10.1016/j.rser.2014.09.016.

Rathjens, George W, Shrink That Footprint, Kimberly Aguirre, Luke Eisenhardt, Christian Lim, Brittany Nelson, Alex Norring, et al. 2014. “Electric Vehicles in Europe - McKinsey.” *Energy* 3 (June): 33. https://doi.org/10.1016/j.retrec.2015.06.004.

REN. 2016. “Technical Data.” 2016. https://www.ren.pt/en-GB/o_que_fazemos/eletricidade/o_setor_eletrico/.

Renewable Energy & Energy Efficiency Partnership. 2012. “Energy Efficiency Technologies and Benefits.” *International Energy Agency*, no. April: 1–29. https://doi.org/10.1787/5k9crzjbpkkc-en.

Rezvani, Zeinab, Johan Jansson, and Jan Bodin. 2015. “Advances in Consumer Electric Vehicle Adoption Research: A Review and Research Agenda.” *Transportation Research Part D: Transport and Environment* 34: 122–36. https://doi.org/10.1016/j.trd.2014.10.010.

Ryan, Richard M., and Edward L. Deci. 2000. “Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions.” *Contemporary Educational Psychology* 25 (1): 54–67. https://doi.org/10.1006/ceps.1999.1020.

Saxton, T. 2012. “Are Taxpayer and Private Dollars Creating Effective Electric Vehicle Infrastructure?” *26th Electric Vehicle Symposium 2012, EVS 2012* 1: 640–51. http://www.scopus.com/inward/record.url?eid=2-s2.0-84877621711&partnerID=40&md5=369a68d9426badf454c733de0fda9dfe.

Schuitema, Geertje, Jillian Anable, Stephen Skippon, and Neale Kinnear. 2013. “The Role of Instrumental, Hedonic and Symbolic Attributes in the Intention to Adopt Electric Vehicles.” *Transportation Research Part A: Policy and Practice* 48: 39–49. https://doi.org/10.1016/j.tra.2012.10.004.

Seiler, Cotten. 2018. “We’re Still Married to the Car – Even Though We Don’t Love It Any More.” *The Guardian*, 2018. https://www.theguardian.com/commentisfree/2018/mar/01/car-automobile-china?CMP=Share_iOSApp_Other.

Shaheen, Susan A., and Adam P. Cohen. 2012. “Carsharing and Personal Vehicle Services: Worldwide Market Developments and Emerging Trends.” *International Journal of Sustainable Transportation* 7 (1): 5–34. https://doi.org/10.1080/15568318.2012.660103.

Sierzchula, William, Sjoerd Bakker, Kees Maat, and Bert Van Wee. 2014. “The Influence of Financial Incentives and Other Socio-Economic Factors on Electric Vehicle Adoption.” *Energy Policy* 68. Elsevier: 183–94. https://doi.org/10.1016/j.enpol.2014.01.043.

Skerlos, Steven J., and James J. Winebrake. 2010. "Targeting Plug-in Hybrid Electric Vehicle Policies to Increase Social Benefits." *Energy Policy* 38 (2): 705–8. https://doi.org/10.1016/j.enpol.2009.11.014.

Smart, John, and Stephen Schey. 2012. "Battery Electric Vehicle Driving and Charging Behavior Observed Early in The EV Project." *SAE International Journal of Alternative Powertrains* 1 (1): 2012-01–0199. https://doi.org/10.4271/2012-01-0199.

Smith, Lydia. 2018. "Renewable Energy Generated 104% of Portugal's Electricity Consumption in March." Independent. 2018. https://www.independent.co.uk/news/world/europe/portugal-renewable-energy-generated-electricity-consumption-march-greenhouse-gas-environment-a8289656.html.

Tesla-Motors-Inc. 2015. *Tesla Inc Annual Report 2015. 11.05.2015.*

The Guardian. 2017. "Inequality Index: Where Are the World's Most Unequal Countries?" *26th April,* 2017. https://www.theguardian.com/inequality/datablog/2017/apr/26/inequality-index-where-are-the-worlds-most-unequal-countries.

The National Budget for 2018. 2017. "Continued Focus on Transport." 25th October. 2017. https://www.regjeringen.no/en/aktuelt/satsingen-pa-samferdsel-fortsetter/id2575351/.

The Regeneration Consumer Study. 2012. "RE:THINKING CONSUMPTION Consumers and the Future of Sustainability." *The Regeneration Roadmap,* 34. http://theregenerationroadmap.com/files/reports/TRR_Rethinking_Consumption.pdf.

The World Bank. 2014. "GDP Growth (Annual %)." World Bank Data. 2014. https://doi.org/10.1016/S2214-109X(15)00065-0.

———. 2018a. "Norway." 2018. https://data.worldbank.org/.

———. 2018b. "Portugal." 2018. https://www.worldbank.org/en/country/portugal.

Thiel, Christian, Adolfo Perujo, and Arnaud Mercier. 2010a. "Cost and CO2 Aspects of Future Vehicle Options in Europe under New Energy Policy Scenarios." *Energy Policy* 38 (11): 7142–51. https://doi.org/10.1016/j.enpol.2010.07.034.

———. 2010b. "Cost and CO2aspects of Future Vehicle Options in Europe under New Energy Policy Scenarios." *Energy Policy* 38 (11): 7142–51.

https://doi.org/10.1016/j.enpol.2010.07.034.

TPN/Lusa. 2017. "Portugal to Have 5,000 Electric Cars by Year-End." The Portugal News Online. 2017. http://www.theportugalnews.com/news/portugal-to-have-5000-electric-cars-by-year-end/40799.

Tran, Martino, David Banister, Justin D.K. Bishop, and Malcolm D. McCulloch. 2012. "Realizing the Electric-Vehicle Revolution." *Nature Climate Change*. https://doi.org/10.1038/nclimate1429.

U.S. Energy Information Administration. 2017. "International Energy Outlook 2017." *International Energy Outlook* IEO2017: 76. https://doi.org/www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf.

United Nations/Framework Convention on Climate Change. 2015. "Paris Agreement." *21st Conference of the Parties*, 3. https://doi.org/FCCC/CP/2015/L.9.

United Nations. 2015. "Adoption of the Paris Agreement." *Conference of the Parties on Its Twenty-First Session* 21932 (December): 32. https://doi.org/FCCC/CP/2015/L.9/Rev.1.

US Department of Energy. 2013. "Report of the Hydrogen Production Expert Panel : A Subcommittee of the Hydrogen & Fuel Cell Technical Advisory Committee." *DoE Fuel Cell Technologies Office*.

Vaughan, Adam. 2017. "Norway Leads Way on Electric Cars." *The Guardian*, 2017. https://www.theguardian.com/environment/2017/dec/25/norway-leads-way-electric-cars-green-taxation-shift.

Vehicle, Electric, and Technology Explained. 2003. *Electric Vehicle Technology Explained*. *New York*. Vol. 42. https://doi.org/10.1002/0470090707.

Wishart, Jeffrey, Richard Barney Carlson, Paul Chambon, and Tyler Gray. 2013. "The Electric Drive Advanced Battery (EDAB) Project: Development and Utilization of an on-Road Energy Storage System Testbed." *SAE Technical Papers* 2. https://doi.org/10.4271/2013-01-1533.

World, One. 2015. "Portugal." 2015. https://www.nationsonline.org/oneworld/portugal.htm.

Zhang, Yong, Yifeng Yu, and Bai Zou. 2011. "Analyzing Public Awareness and Acceptance of Alternative Fuel Vehicles in China: The Case of EV." *Energy Policy* 39 (11): 7015–

24. https://doi.org/10.1016/j.enpol.2011.07.055.

Zhou, Yan, Todd Levin, and Steven Plotkin. 2016. “Plug-in Electric Vehicle Policy Effectiveness: Literature Review.” *U.S. Department of Energy Laboratory Managed by UChicago Argonne, LLC under Contract DE-AC02-06CH11357*. http://www.osti.gov/scitech/.