Economics of E-Mobility

A COMPARATIVE STUDY OF THE TOTAL COST OF OWNERSHIP OF ELECTRIC VEHICLES AND INTERNAL COMBUSTION ENGINE VEHICLES

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1 Introduction

1.1 Motivation

The rate at which the Earth's temperature has been rising has caused severe climate changes. The severity of these changes would continue to increase, unless immediate action is taken. Greenhouse gases, produced from the burning of fossil fuels, trap radiation from the sun and cause an increase in the Earth's temperature, and cause global warming. The increase in carbon dioxide levels of the Earth is therefore a huge concern and on the agenda of countries around the world.

In a study conducted by the European Environment Agency in 2013, it was concluded that transport is the second largest contributor to the increase in greenhouse gases in Europe, the first being the power generation sector. Furthermore, the European Commission has reported that road transport is among the few sectors which have shown a rate of increase in emissions. It is also stated that passenger cars make up for about 12% of the carbon dioxide emissions in the EU (EC, 2015). The technological improvements in the vehicle industry, although noteworthy, have not been able to reduce the level of the carbon dioxide emissions due to the increases in vehicle sizes and the number of vehicles.

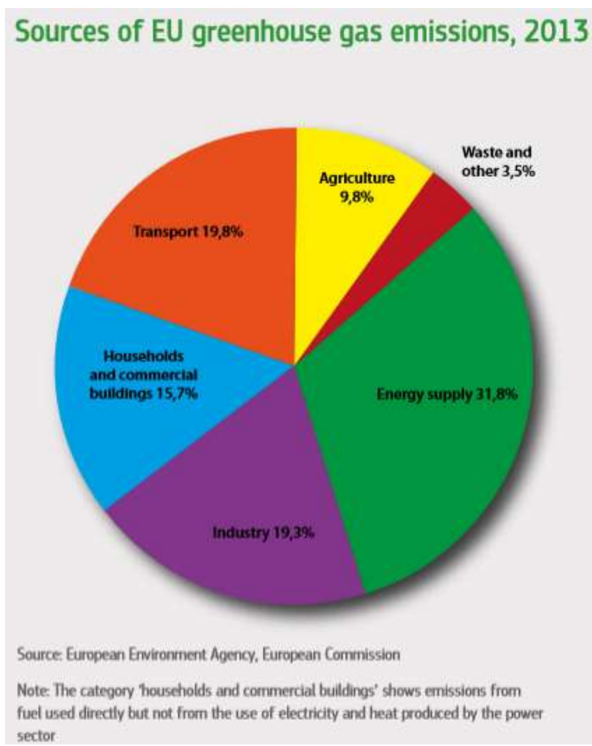


Figure 1.1. Sources of EU greenhouse gas emission in 2013 (EC, 2015)

In light of this knowledge, the EU Regulation (EC) No 443/2009 was passed to establish emission performance standards for new passenger cars to reduce carbon dioxide emissions from light duty vehicles. This Regulation limits the average carbon dioxide emissions for new passenger cars at 130 g CO_2/km, which would be achieved by improvement in vehicle technology. A target of 95 g CO_2/km has been set for 2020 onwards (EU, 2014). These emission reduction targets, have increased the pace of the shift of the automobile industry towards electric vehicles. The requirement of a decrease in carbon dioxide emissions by 2020 has become a major driving force for the development of the electric vehicle market.

Electric vehicles have been labelled as a technology with a huge potential to massively reduce the carbon dioxide emissions of the road transport industry.

This promising role of the electric vehicle in the reduction of carbon dioxide emissions is the main motivation behind this research paper.

Economic overview
Conventional cars need more energy than EV so they have lower efficiencies. (Döring, 2011).
The big three ecological aspects to use EVs are

- more efficiency (loss energy consumption)
- less noisy
- zero emission and no dust

We can only use the ecological advantage of EVs if we produce the energy from renewable energy resources. (Döring, 2011)

In Austria we used 33.1% of energy from renewable sources in 2014.
(eurostat, 2016)
The targets for renewable sources for 2020 are 34% of share of energy generated in gross final energy consumption, 33% heating and cooling, 71% electricity and 11,5% for transport. (IEA, kein Datum)
Another problem is the lithium battery that can only use 86% for power train and 14% we loose by chemical reaction as well as the limited charging cycles. The production of these batteries use a lot of energy that produce CO2 again. (Asendorpf, 2009)
In total we have an 80% lower carbon dioxide emission including production and energy generation than conventional cars. (Climate and Energy Fund, 2015)

1.2 Core Objective

Although Electric Vehicles (EV) show great potential, there are certain parameters which limit their appeal in the current automobile market when compared to conventional cars. The most important issue when dealing with the economics of EVs is the development costs of batteries.

This paper focuses on two types of vehicles; Battery Electric Vehicles (BEV) and Internal Combustion Engine Vehicles (ICEV). The paper will take into account only medium sized vehicles. The BEV and ICEV used in this study are Nissan Leaf and Nissan Pulsar respectively.

The main objective of this research paper is to analyse the total cost of ownership (TCO) of EVs and compare it to that of the ICEV. Furthermore, the impact of different government policies on the TCO of EVs and ICEVs will be examined.

The TCO calculations will be performed for the Czech Republic, and Austria.

2 Current State of Mobility

2.1 Czech Republic

2.1.1 Conventional Cars

The number of total cars in the Czech Republic has been given in figure 2.1. We observe an increase in the number of passenger cars between the years 2000 and 2013.

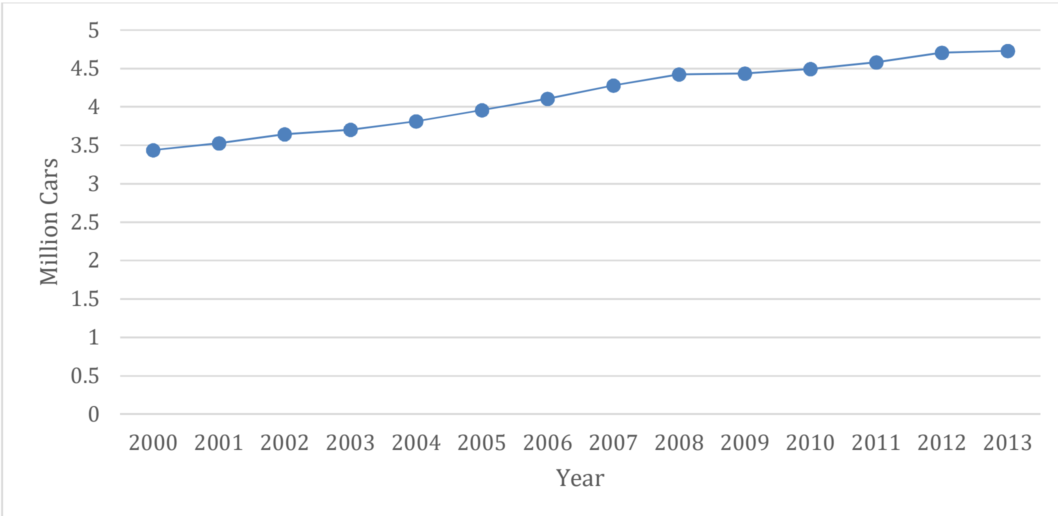


Figure 2.1. Number of passenger cars in the Czech Republic (ODYSSEE Database, 2014)

The statistical data available indicates that gasoline cars are preferred over diesel cars. Figure 2.2 shows the number of gasoline and diesel passenger cars in the Czech Republic between 2000 and 2013. It is clear that throughout this period the number of gasoline cars has always been much higher than that of diesel cars.

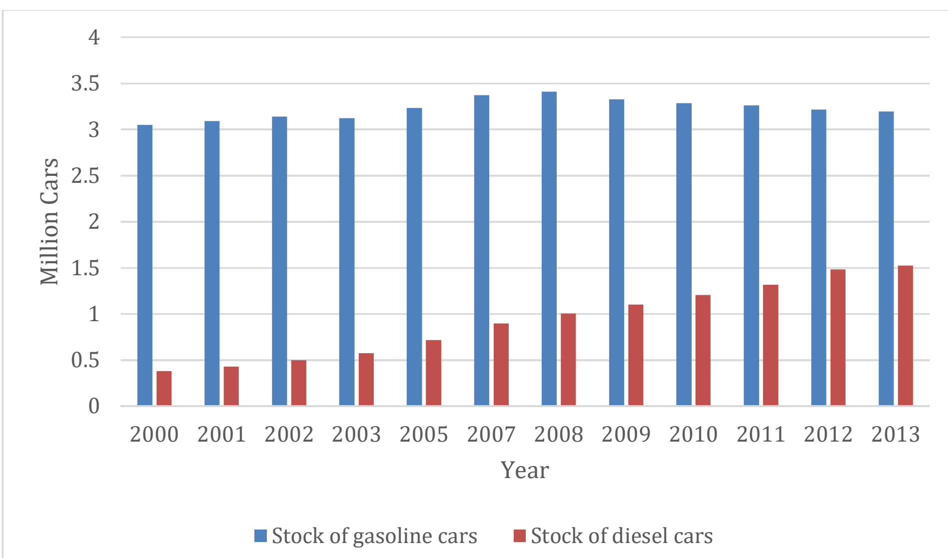


Figure 2.2. Number of gasoline and diesel passenger cars in the Czech Republic (ODYSSEE Database, 2014)

The number of new cars registered in the Czech Republic between 2000 and 2013 further confirm the popularity of gasoline cars. Figure 2.3 shows the total number of new cars registered in the Czech Republic. The number of newly registered gasoline and diesel cars is also given for comparison.

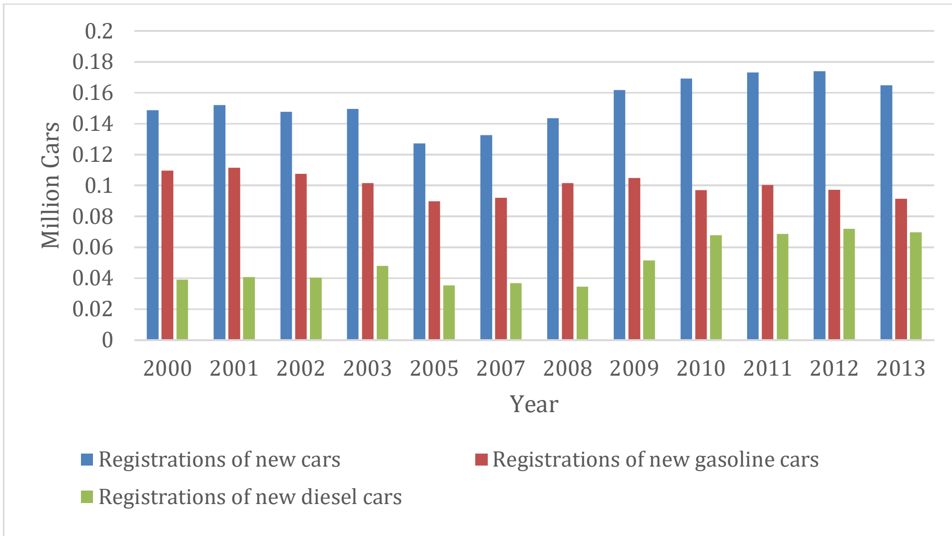


Figure 2.3. Registration of new passenger cars in the Czech Republic (ODYSSEE Database, 2014)

The annual distance travelled by passenger cars in the Czech Republic is shown in figure 2.4. An average of this data was taken and used in the calculation of the total cost of ownership.

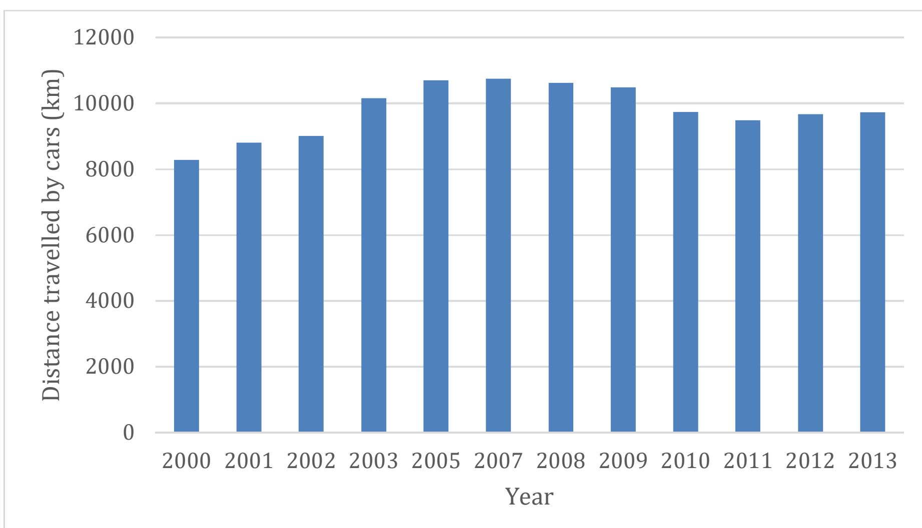


Figure 2.4. Annual distance travelled by passenger cars in the Czech Republic (ODYSSEE Database, 2014)

2.1.2 Electric-Vehicles

The current market share of EVs in the Czech Republic has been given in figure 2.5. The graph shows the market share of Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV) separately.

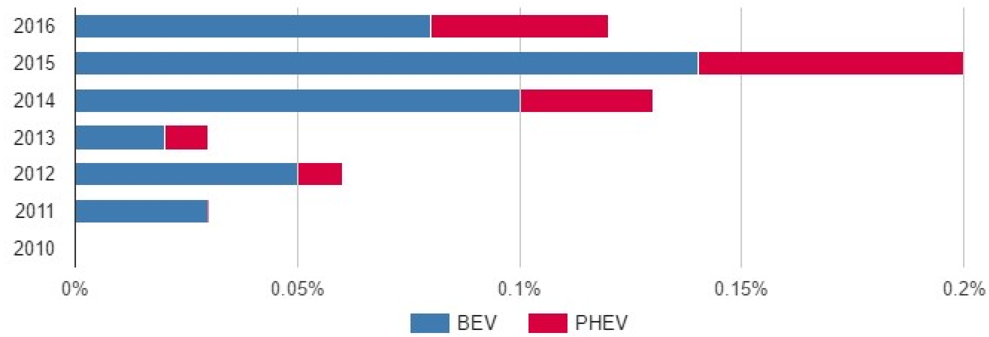


Figure 2.5. Market share of electric cars, BEV and PHEV in the Czech Republic (EAFO, 2016)

In order to understand the general trend of EV ownership in the Czech Republic, we have to analyse the number of newly registered EVs. Figure 2.6 shows the number of newly registered electric cars in the Czech Republic.

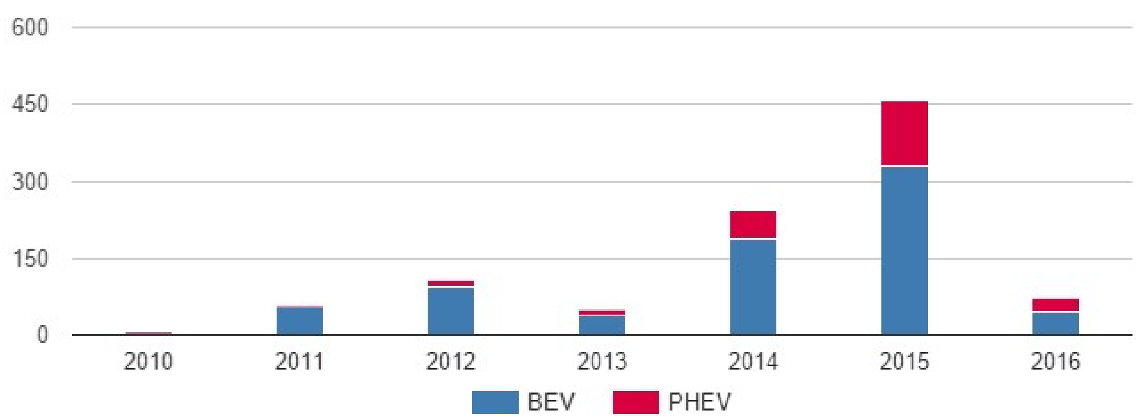


Figure 2.6. Registration of new electric cars, BEV and PHEV, in the Czech Republic (EAFO, 2016)

A major factor reducing the appeal of EVs is the lack of infrastructure. Hence, it is crucial to evaluate the current state of charging stations and their locations around the Czech Republic. Figure 2.7 shows an increase in the number of charging stations.

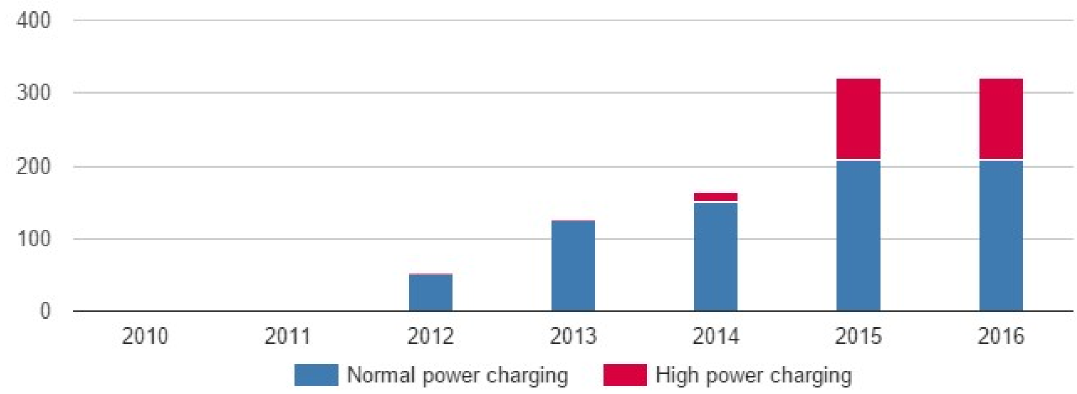


Figure 2.7. Number of publicly accessible charging positions in the Czech Republic (EAFO, 2016)

The current location of the charging stations around the Czech Republic is given in figure 2.8. The highest number of charging stations are located in Prague.

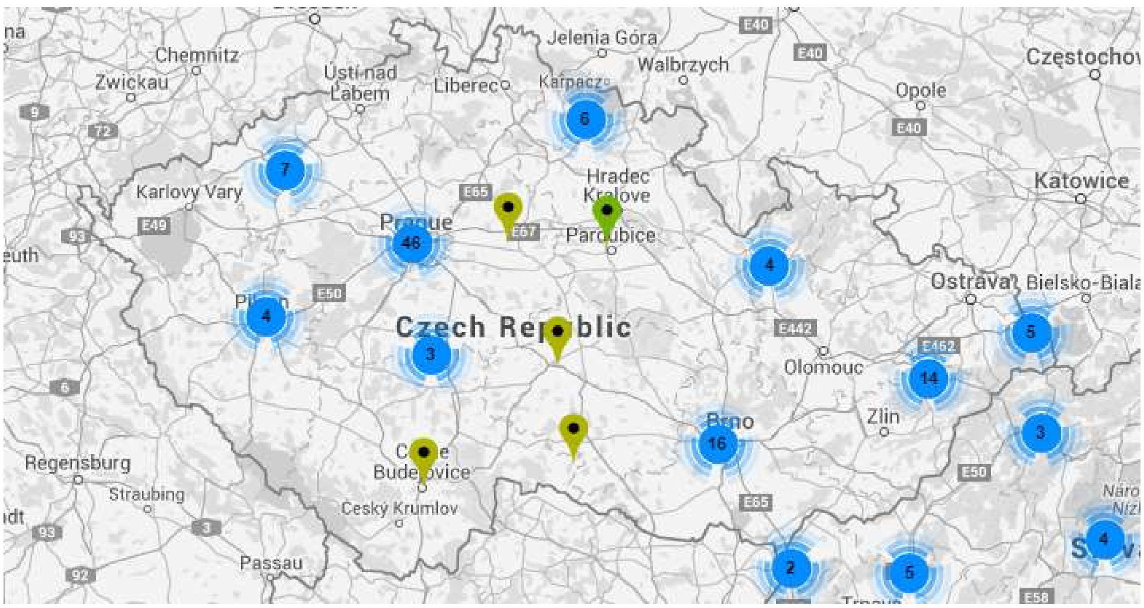


Figure 2.8. Czech Republic Charging Stations map (EVMAP, 2016)

In order to increase the sales of EVs in the Czech Republic, the government has introduced some tax exemptions. The EV is exempt from registration tax and ownership tax. Hence, the owner of an EV is not required to pay registration tax and is also exempt from road tax (ACEA TAX GUIDE, 2016).

2.2 Austria

2.2.1 Conventional Vehicles

Since the last 13 years the number of passenger cars in Austria has been rising linearly over the years.

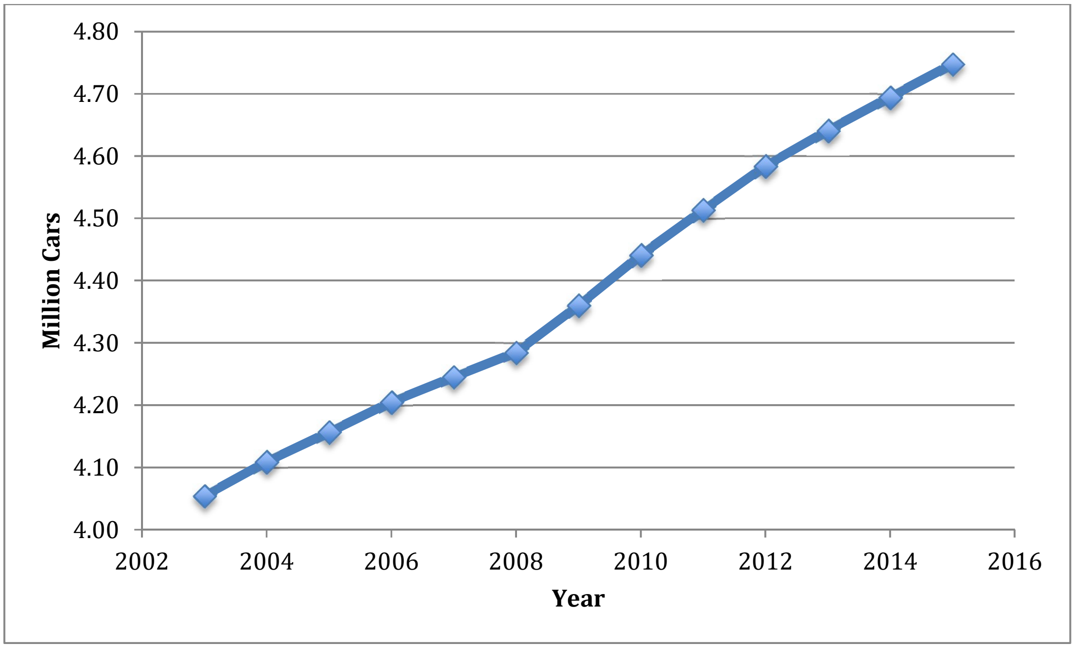


Figure 2.9 Number of passenger cars in Austria (STATISTICS AUSTRIA, 2016)

The years before 2004 the market share of gasoline cars was higher than diesel cars. The big change where diesel cars were preferred over gasoline cars was in the year 2005. Till now the market share of diesel cars have been increased and the market share of gasoline cars have been decreased. Figure 2.10 illustrates the market share of diesel and gasoline over the last 12 years.

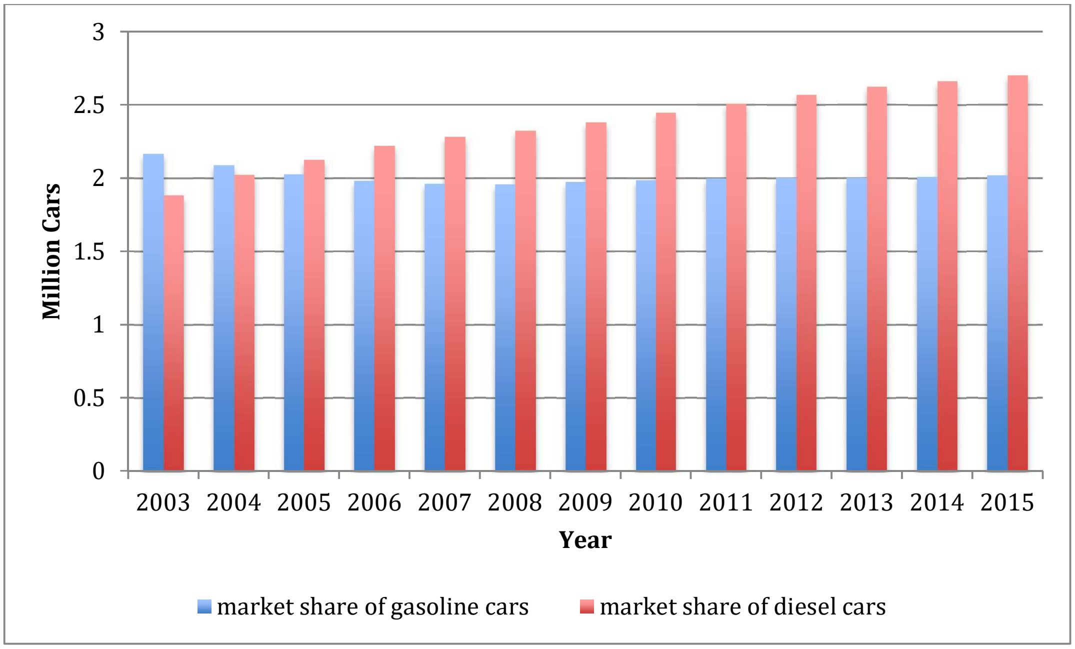


Figure 2.10 Market share of gasoline and diesel cars in Austria (STATISTICS AUSTRIA, 2016)

From 2004 till 2008 the numbers of new registrated cars decreased. For example since 1.7.2008 they developed a bonus/malus regulation in Austria. Therefore you have to pay less if the car observe the reference values. (ÖAMTC, 2014) The highest amount of new registrated cars over the last 12 years were diesel cars.

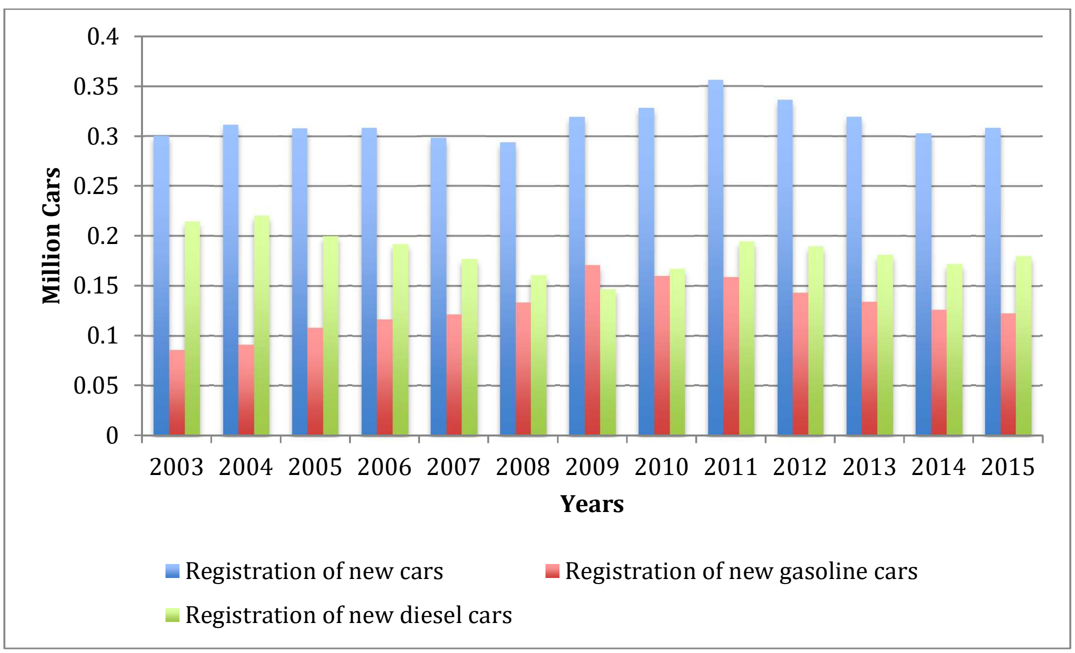


Figure 2.11 Registration of new passenger cars in Austria (STATISTICS AUSTRIA, 2016)

2.2.2 Electric Vehicles

Charging stations

In Austria we have currently 2.663 recharging points which are depicted in Figure 2.12. . The yellow ones are fast charging stations that mean the charging power is higher than 22kW. With the increasing numbers of E-cars, we have a rising demand of charging stations.

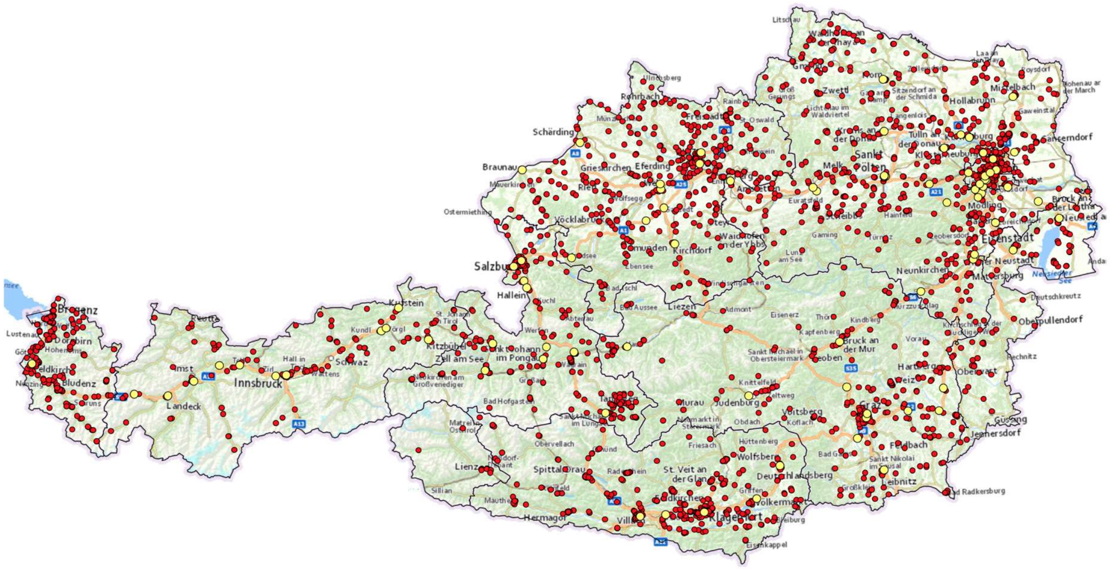


Figure 2.12. (Measures, 2016)

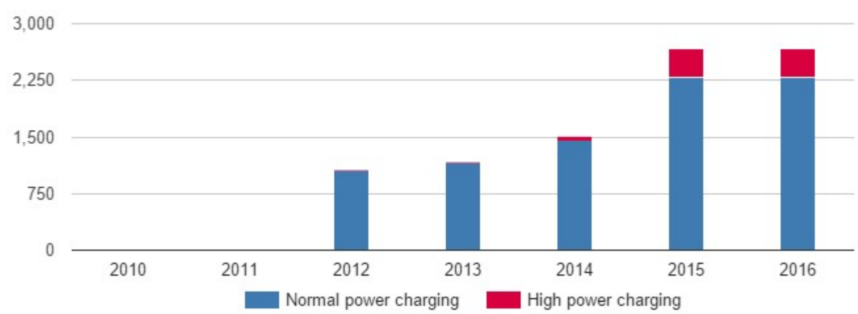


Figure 2.13. Number of publicly accessible charging positions.

Fuel types or power source	% share (2015)	% share (2012)	% change
Diesel	58,3	56,4	-5,2
Petrol incl. flex-fuel	39,8	42,7	-14,3
Hybrid (HEV)	1,1	0,6	61,8
Electric powered (BEV)	0,5	0,1	292,7
Plug-in Hybrid (PHEV)	0,4		

Table 2.1. (STATISTICS AUSTRIA, 2016)

Compared to 2012 0.13% the share of new registered EVs increased to 0.9% in 2015. BEVs are more common than PHEVs. This is a good way to change the CO2 emission. In Europe we have 31% of the global market from EVs.

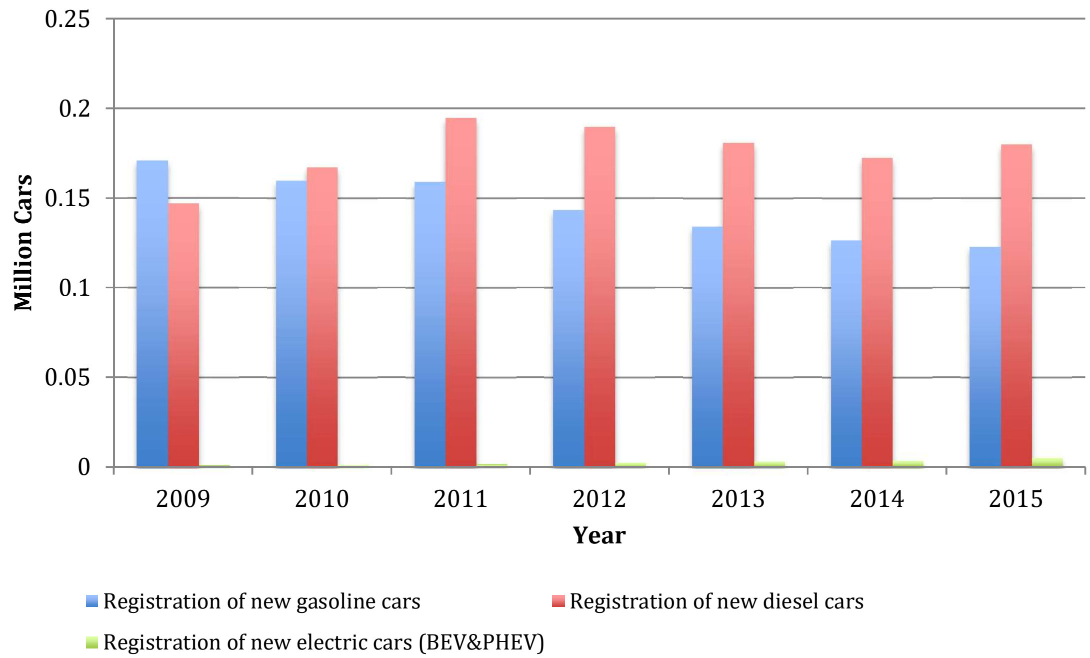


Figure 2.14. Registration (STATISTICS AUSTRIA, 2016)

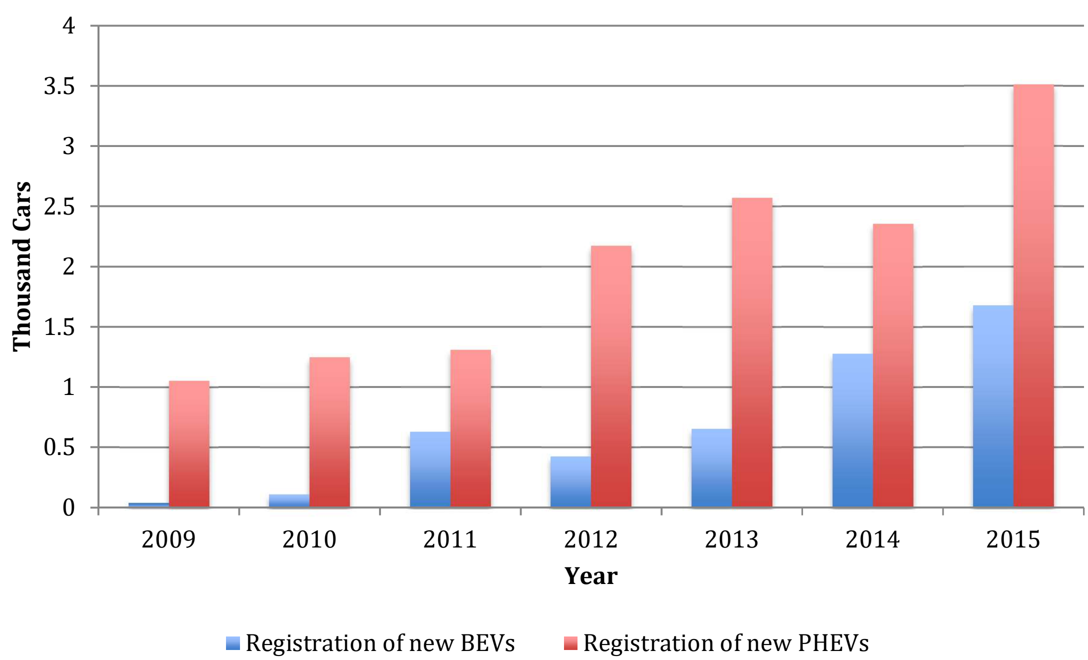


Figure 2.15. Registration (STATISTICS AUSTRIA, 2016)

Figure 2.15 illustrates the gain of registrations of new electric cars and a descent for gasoline and diesel cars over 6 years.

Electric cars have a very small share of registrations compared to other conventional cars.

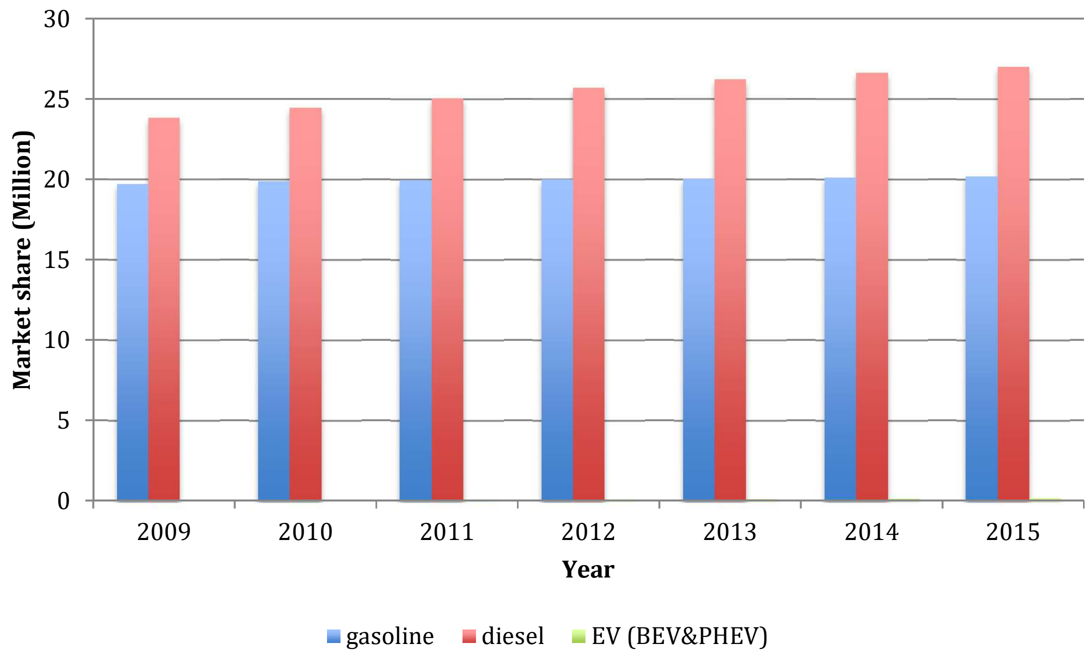


Figure 2.16. Market share (STATISTIK AUSTRIA, 2016)

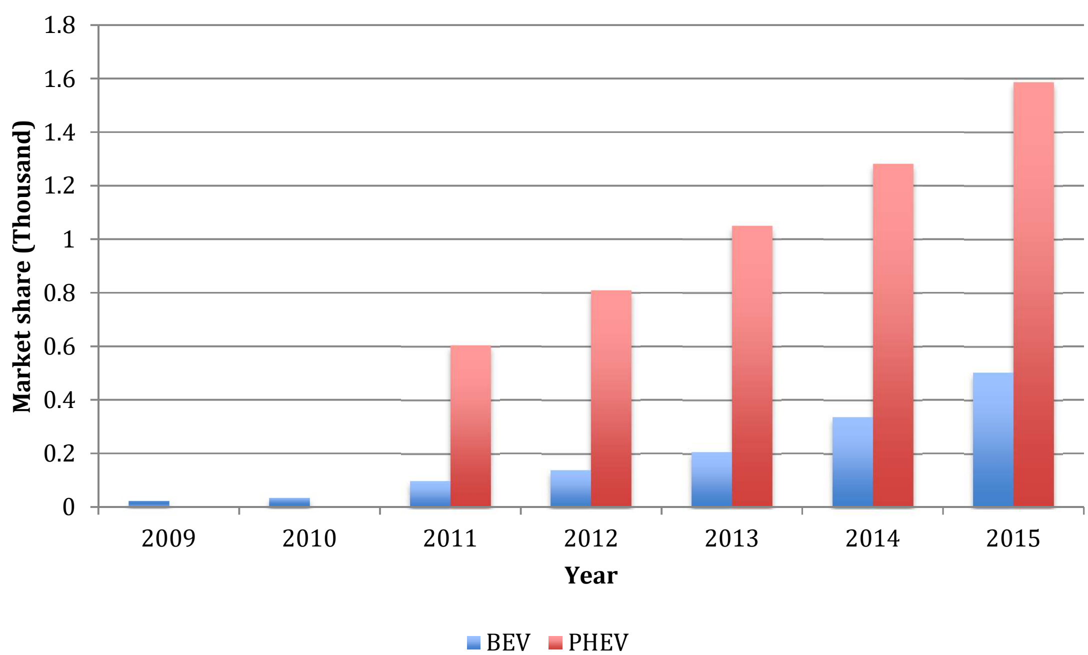


Figure 2.17. Market share (STATISTIK AUSTRIA, 2016)

In Figure 2.17 we can see the growing market share of PHEVs and BEVs. In year 2009 and 2010 the source "Statistik Austria" has no values for PHEVs.
For 6 years the increase of market share for gasoline was not very big compared to diesel.
According to "Statistik Austria" in 2015 approximately 0.1% of all cars are EVs.
The registration of new electric vehicles in 2015 were 0.9% and in 2012 0.13%.

For six years Austria has seven "model regions of electric mobility" to develop a new business and mobility model, provide renewable energy, geographical conditions and buying 1,500 vehicles as well as 1,600 charging stations.
These seven models are

- VLOTTE (Vorarlberg)
- ElectroDrive Salzburg (Salzburg)
- e-mobility on demand (Wien)
- Großraum Graz (Graz)
- e-pendler niederösterreich (Niederösterreich)
- E-LOG Klagenfurt (Kärnten)
- E-Mobility Post (Wien)

(Climate and Energy Fund, 2015)
These seven model regions are illustrated in Figure 2.18.

Figure 2.18. Location of the model regions of electric mobility (Climate and Energy Fund, 2015)

2.3 European Union

2.3.1 Conventional Vehicles

In the last years there is a constantly increase of cars in Europe. Especially diesel cars increased over 50 per cent over the last 13 years whereas the stock of gasoline cars fell a little bit.

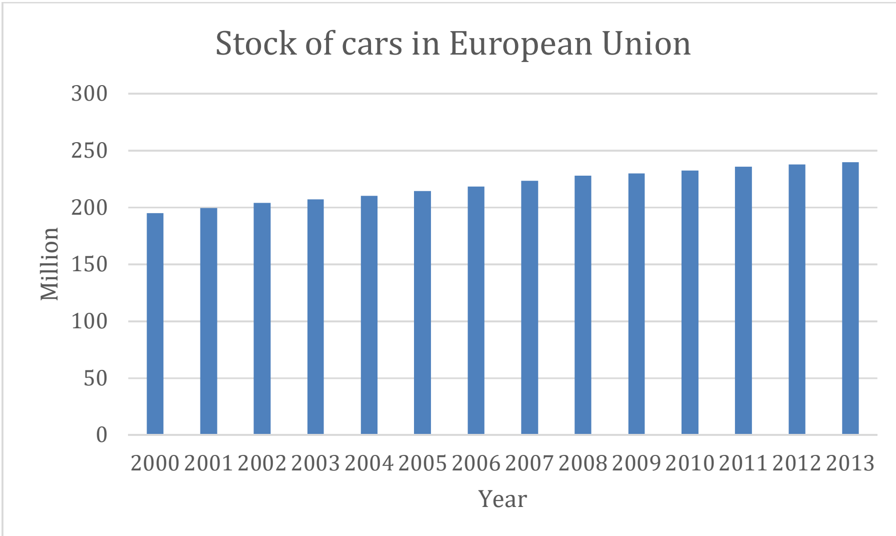


Figure 2.19. Stock of cars in EU (ODYSSEE Database, 2014)

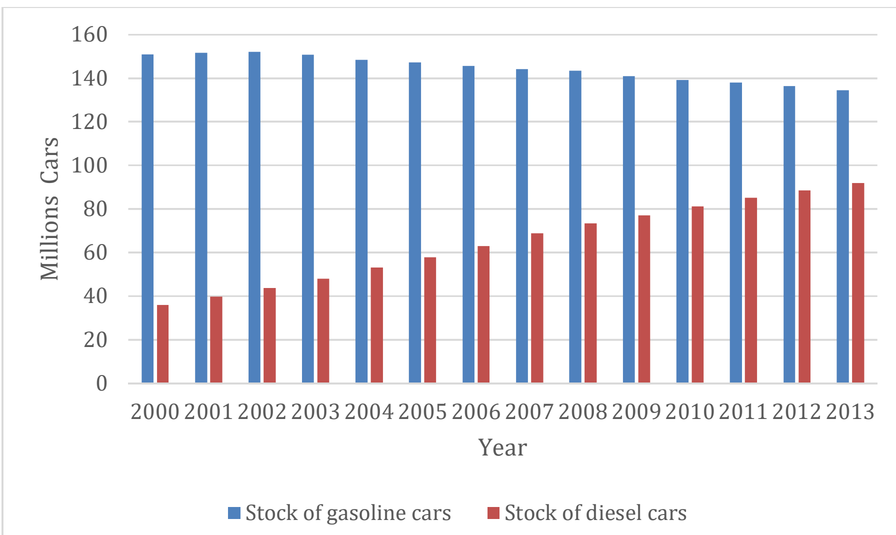


Figure 2.20. Stock of gasoline and diesel cars in the EU (ODYSSEE Database, 2014)

2.3.2 Electric Vehicles

Electric Vehicles are getting more popular over the last years especially PHEVs. Currently the PHEVs are more in common than the BEVs.
The data of the electric Vehicles of the year 2016 aren't complete yet.

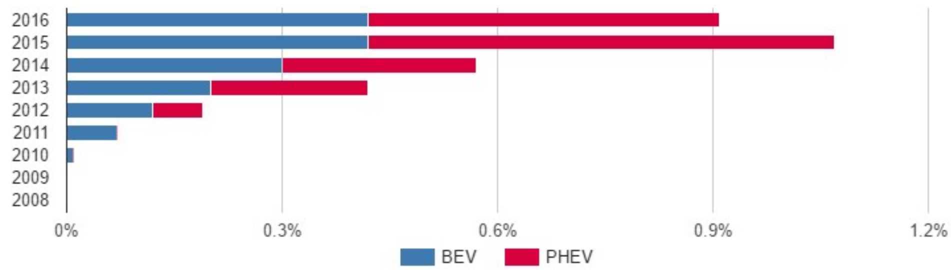


Figure 2.21. Market share of EVs in the EU (EAFO, 2016)

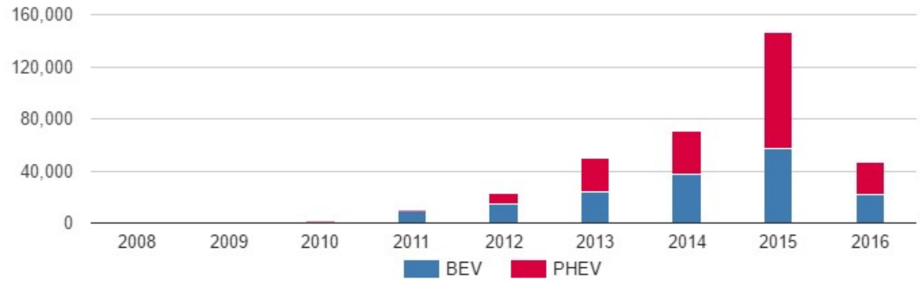


Figure 2.22. New registration Electric Vehicles in the EU (EAFO, 2016)

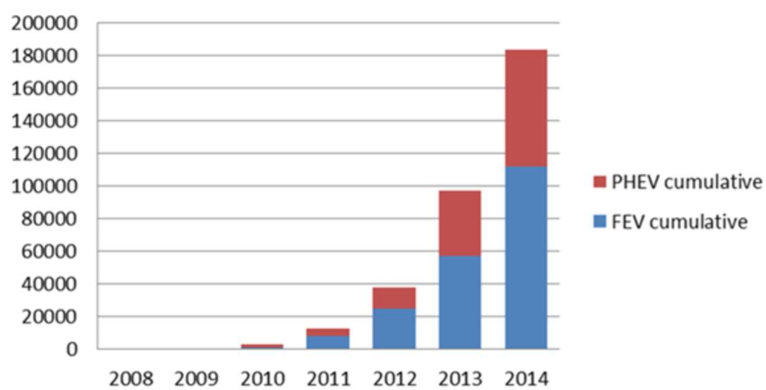


Figure 2.23. European EVs on the road (Witkamp, 2015)

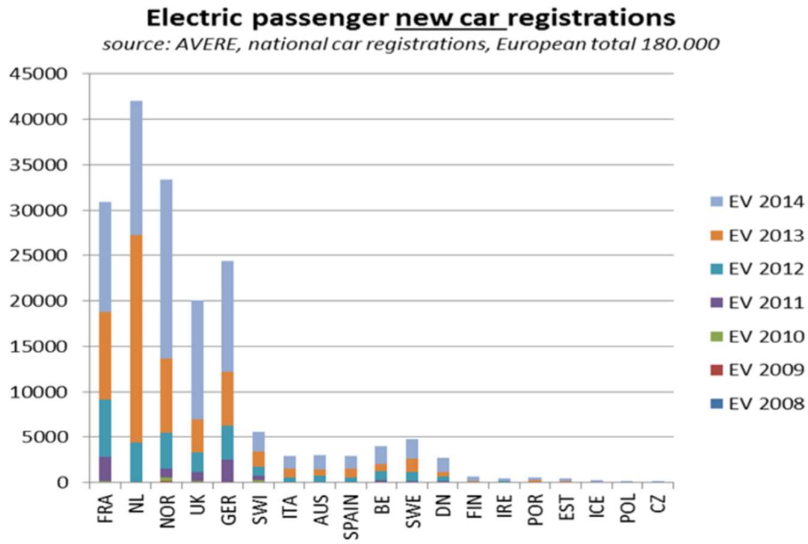


Figure 2.24. Electric passenger new car registrations (Witkamp, 2015)

Figure 2.24 shows an increase of new electric passenger car registrations in the last years. Especially France, Netherlands, Norway, UK and Germany are the leading countries.

In Norway there is a rapid increase of electric vehicles. They want that all new cars, busses and other vehicles are sustainable, to divide the emission in half till 2025. To reach this goals they support the project with tax reliefs for electrical cars and other goodies like free parking. (manger magazin, 2016)

Also politicians in Netherlands have voted to ban sales of new diesel and petrol cars starting in 2025. (The Guardian, 2016)

3 Methodology

3.1 Components of the Total Cost of Ownership

3.1.1 Battery costs

We use three different scenarios, which were created, from AG2 from Nationale Platform Elektromobilität (NPE) in year 2011. These three scenarios are called base, best and worst.

We create a one-factor learning curve, because the battery price is changing by learning and scaling effect of production.
The learning rate describes dynamic reduction in costs on the basic of learning.
Scaling effect means the increasing in production result in lower cost per piece.

$$c = K_0(1 - L)^{log_2[1+r(t-t_0)]}$$

Equation 3.1 Battery costs equation (Plötz, Gnann, Kühn, & Wietschel, 2013)

c	Battery costs
L	learning rate
(1-L)	cost reduction potential
t	time
r	gradient parameters of the learning rate
t_0	start time (we use 2011)
K_0	cost of the first unit of production

scenario	K0	L	r
Base	798,4	0,198	2,818
Best	698,1	0,207	2,27
Worst	898,2	0,197	3,04

Table 3.1. Parameters for battery price learning curve (Plötz, Gnann, Kühn, & Wietschel, 2013)

scenario	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Base	798,40	521,20	437,11	390,53	359,41	336,52	318,67	304,19	292,09	281,76
Best	698,10	469,62	393,67	350,94	322,22	301,05	284,52	271,11	259,91	250,35
Worst	898,20	577,35	483,41	431,72	397,28	371,99	352,28	336,29	322,95	311,57

Table 3.2. Smoothed battery prices (€/kWh) excluding VAT (Plötz, Gnann, Kühn, & Wietschel, 2013)

For more details please look into the paper (Plötz, Gnann, Kühn, & Wietschel, 2013).

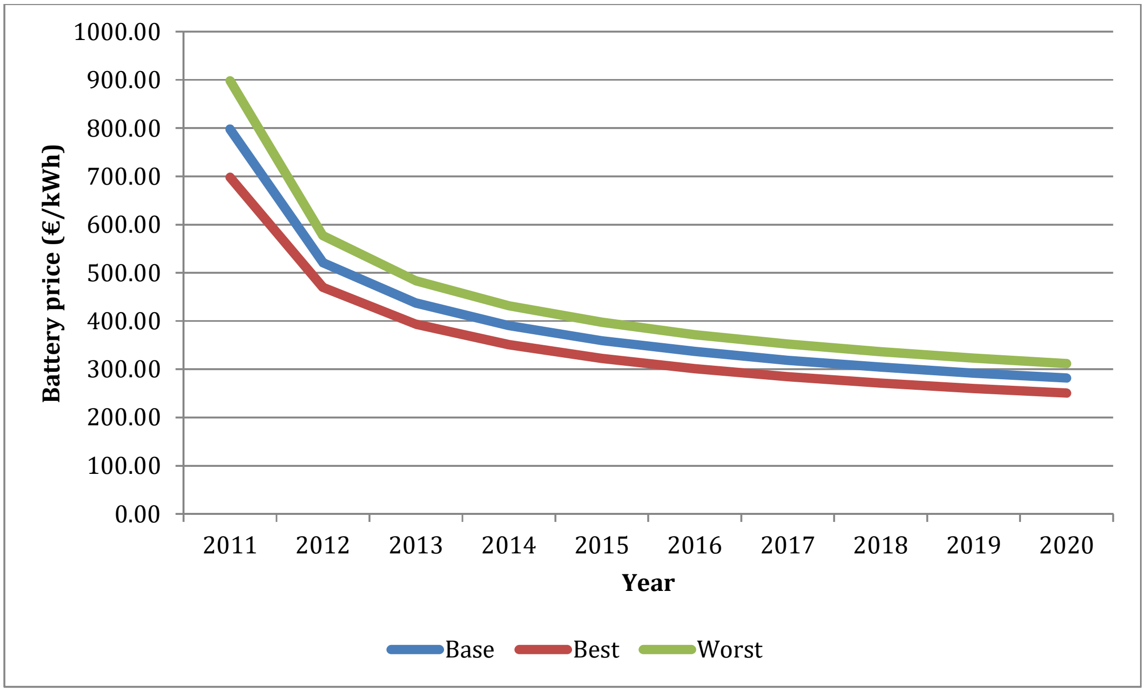
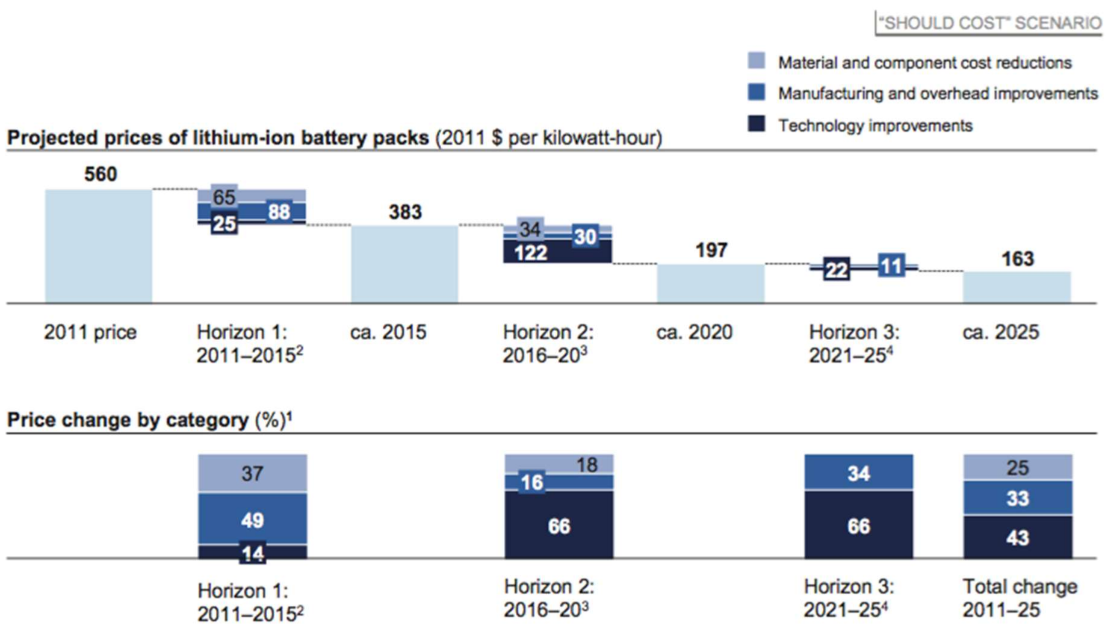


Figure 3.1. Three different scenarios for battery prices excluding VAT (Plötz, Gnann, Kühn, & Wietschel, 2013)

With this formula we got a smoothed battery price trend.
Figure 3.1 illustrates very similar prices compared to the scenario from NPE (Plötz, Gnann, Kühn, & Wietschel, 2013).



1 Change from previous horizon (%).
2 Assumes plant scale of 100,000 battery packs per year, cell-capacity increase of 10%, and expected materials cost and margin compression.
3 Assumes continuous manufacturing improvement of 6% for battery-management system and 3% for all other pack elements, cell-capacity increases of 82% from today, and expected materials cost and margin compression.
4 Assumes continuous manufacturing improvement of 6% for battery-management system and 3% for all other pack elements, and cell-capacity increases of 112% from today.

Figure 3.2. Lithium-ion battery price improvements scenario. (Hensley, Newman, Rogers, Russell Hensley, John Newman, Matt Rogers, Mark Sh, & Shahinian, 2012)

In this scenario we see the decreasing costs for lithium-ion batteries. In horizon 2 between 2016 and 2020 the capacity-boosting battery technology will drive the majority of reduction ant therefore the manufacturing and overhead improvements as well as the material and component costs will reduce. If this scenario is true the costs for batteries should be 163$/kWh.

Li-ion
Lithium
Nickel (LiNiO2)
Cobalt (LiCoO2)
Manganese (LiMnO4)
Phosphate (LiFePO4)
Aluminum (Li(NiCoAl)O2)
Iron/steel (LiFePO4)

Table 3.3. Li-ion Battery raw materials (Gerssen-Gondelach & Faaij, 2012)

	Cathode		Anode	Total	
Li-ion	$Li(NiMnCo)O_2$	$LiFePO_4$	Graphite		
€/kg	34	18	20		
€/kWh	68	37	19		
				87	$Li(NiMnCo)O_2$
				56	$LiFePO_4$

Table 3.4. Li-ion battery raw material costs (Gerssen-Gondelach & Faaij, 2012)

In Li-ion batteries, cathode materials cobalt is a major component and represent a high share of total costs (Gerssen-Gondelach & Faaij, 2012).

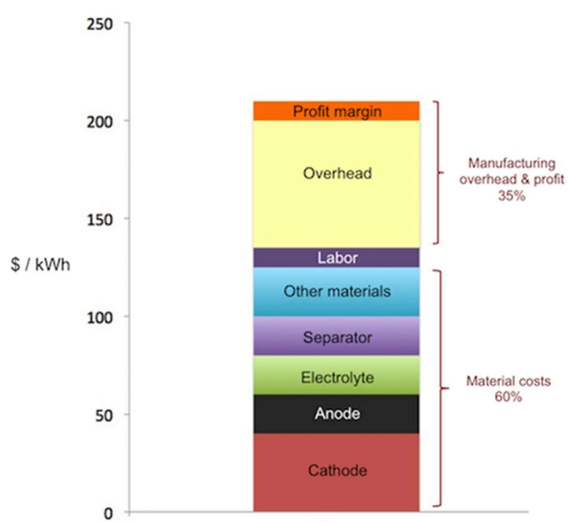


Figure 3.3. Cost components of lithium-ion battery (Qnovo, 2016)

The material costs about 60% of the total cost. For lithium-ion batteries made using lithium-cobalt oxide cathodes (LCO, used in consumer devices) or nickel-cobalt-aluminium cathodes (NCA, used in Tesla).

3.1.2 Other impact parameters

Total cost of ownership highly dependent on many other parameters, which may differ for EVs and ICEVs. The various factors impacting the TCO of vehicles have been explain in the following sections.

3.1.2.1 Oil and Electricity Prices

Electricity prices are a major cost defining factor for EV. In the case of ICEVs this factor is oil prices. The calculation of annual cost of operation involves the determination of the annual fuel cost. Therefore, any fluctuation in the price of electricity or oil would result in a change in the annual fuel cost of the EV and ICEV respectively. The resulting change in the annual cost of operation would consequently change the TCO of the vehicle. The

3.1.2.2 Vehicle Efficiency

The efficiency of the vehicle is the ratio of the distance travelled per unit of fuel consumed. It is a component of the annual fuel cost. Therefore, TCO obtained for vehicles with different efficiencies would also be different. The efficiency is inversely related to the TCO that is, the higher the efficiency of the vehicle the lower the TCO.

3.1.2.3 Taxes and Government Incentives

The TCO of vehicles is comprised of two main components; the initial cost, and the annual cost of operation. The different kinds of taxes could be categorized under these two cost components, depending on whether they are paid annually or if they are a one-time payment at the time of purchase of the vehicle. Registration tax is one which is included in the initial cost. Some of the taxes included in the annual cost of operation are road tax and carbon emission tax, for ICEVs. Value Added Tax (VAT) could be a component of both the initial cost and the annual cost of operation. An increase in any kind of tax would result in an increase in the TCO.

Government incentives, on the other hand, are those policies which encourage the purchase of the good they are intended for. This could result in a decrease in one of the components of the cost of ownership, resulting in a decreased TCO. Government subsidies and exemption from certain taxes are some of the incentives implemented in some countries.

3.1.2.4 Economic Factors

It is vital to include economic factors to ensure the accuracy of the calculated TCO. Inflation rates, discount rates, and interest rates are a few of the economic factors which may have an impact on the TCO. However, it is important to state that the TCO model designed for this study is based on the assumption that the vehicle is purchased without any loans. Therefore, this study does not take into account the impact of interest rates on the TCO.

3.1.2.5 Fixed Costs

The annual cost of operation has another component; fixed cost. The fixed cost component takes into account those costs which do not depend on vehicle usage. Road tax, insurance, vignette, Regular Technical Inspection (RTI), Regular Emission Measurements (REM), and the cost of maintenance are the components of fixed cost used in this study. An increase in any of the components of the fixed cost would result in an increase in the TCO.

3.1.2.6 Average Annual Mileage

The average annual distance travelled determines the annual fuel cost as well as the TCO per km driven over the entire period of ownership. Since this factor also determines the time of battery change, it is a key component when calculating the TCO of EVs.

3.1.2.7 Holding Period

The holding period of a vehicle is the number of years from the time the vehicle is purchased and the time when it is resold. In this study we have assumed that the holding period of the vehicle is equal to the entire lifetime of the vehicle, and that it has no resale value at the end of this period. The holding period is also a major cost defining factor and the longer the holding period the lower the TCO of the vehicle.

3.2 Total Cost of Ownership Model

The Total Cost of Ownership (TCO) model used in this study allows the calculation of the total costs pertaining to owning an EV, and an ICEV, in Czech Republic and Austria. The TCO was divided into two major categories; the Initial Cost at the time of the purchase, and the annual cost of operation. Hence, all the possible costs of owning a vehicle were included in one of these categories. Figure 3.4 shows a diagram of the cost structure used in this study. The further breakdown of costs which might vary for the countries being compared has been shown in their designated subsections.

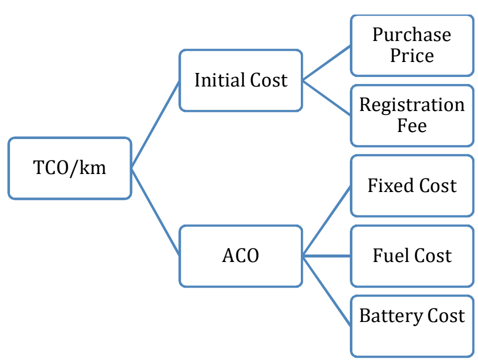


Figure 3.4. Diagram of the Cost Structure.

The equation used to calculate the TCO has been given in equation 3.2. It shows the TCO per kilometre driven.

$$TCO = \frac{IC + \sum_{n=1}^{N} \frac{ACO_0(i+1)^{n-1} + BC}{(1+r)^n}}{N * AAD} \qquad [€/km]$$

Equation 3.2. TCO Model equation - Adapted from: (Wu, Inderbitzin, & Bening, 2015)

Where;

IC	Initial Cost [Euros]
ACO_0	Annual Cost of Operation in Year 1 [Euros]
BC	Battery Cost [Euros]
i	rate of inflation
r	discount rate
n	year
N	Lifetime of the Vehicle/Holding Period [years]
AAD	Average annual distance travelled [km]

The annual cost of operation was calculated such that it takes into account the rate of inflation for each year. The annual cost of operation obtained for each year for the total lifetime of the vehicle was then converted to its present value. However, the effect of inflation has not been included in the battery costs arising as a result of changing the batteries. The economic parameters involved in the calculation will be presented in the designated subsection of each country.

As shown in Figure 3.4, ACO was further divided into three subcategories; fixed costs; fuel costs; and battery costs.

The components of the fixed costs, which might differ for the countries being studied, have been given in the following subsections assigned to each countries.

The battery cost was obtained from the forecast of prices estimated in the previous section, explaining the battery costs and their development. The data to be used was selected on the basis of the lifetime of the battery. Hence, the price was selected depending on the year in which the battery needs to be changed. However, since the cost of battery does not include VAT, the battery costs with the relevant percentage of VAT included were used for the TCO calculation of Czech Republic and Austria. The TCO was calculated for each of the described scenarios of battery costs. Furthermore, the effect of inflation has been ignored for battery costs. It is evident that in the case of ICEVs this cost will be omitted.

The fuel cost of the vehicles was calculated using a simple approach and the equation has been given in equation 3.3. The fuel consumption for an EV would be in kWh, and for an ICEV in litres.

$$\text{Fuel Cost} = (\text{Fuel efficiency of vehicle}) * (\text{AAD}) * (\text{Price of Fuel})$$

Equation 3.3. Fuel cost

The vehicles used in this study are Nissan LEAF Visia and Nissan Pulsar Acenta. The vehicles will represent the BEV and the ICEV respectively. Tables 3.3 and 3.4 give the technical specifications of the mentioned vehicles.

Nissan LEAF Visia				
Power	80	kW		
Torque	254	Nm		
Range	199	km		
CO2 Emission	0	g/km		
Electrical Efficiency	0,15	kWh/km		
Battery kWh	24	kWh		
Battery Life-Time	5	years	100000	km

Table 3.3. Technical specifications of EV, Nissan LEAF Visia (NISSAN Leaf, 2016)

Nissan Pulsar Acenta – DIG-T-115		
Power	85	kW
Torque	165	N.m
Fuel Type	Petrol	
CO2 Emission	119	g/km
Fuel Efficiency	0.062	l/km
Displacement	1,2	cc

Table 3.4. Technical specifications of ICEV, Nissan Pulsar Acenta (NISSAN Pulsar, 2016)

Assumptions:

- The car has a lifetime of 15 years and at the end of this period its resale value is assumed to be zero.
- The discount rate has been set as 2% for both countries, but a sensitivity analysis has also been conducted for a range of discount rates.
- The vehicle is bought without any bank loans. Hence the effect of interest rates has not been included. This is a valid assumption as the type of fuel of the car purchased has little or no impact on bank loans, and therefore it is acceptable to say that it is not a cost defining parameter.
- The cost of battery is not effected by inflation.
- The costs arising due to any accidents or damage to the vehicle are not a cost defining parameter, and have been neglected.

3.2.1 TCO Model for the Czech Republic

The TCO model defined in the previous section was used for Czech Republic. The IC and ACO parameters of the TCO model for Czech Republic were calculated by distinguishing between costs of car ownership that occur at time of purchase of the vehicle, and costs which occur annually or at certain intervals during the ownership period. The IC was obtained by adding the purchase price to the registration fee, as shown in the general model in Figure 3.4.

The battery cost and fuel cost component of the ACO was calculated as explained. The calculation of fixed cost for Czech Republic included the road tax, insurance, vignette, Regular Technical Inspection (RTI), Regular Emission Measurements (REM), and the cost of maintenance. Figure 3.5 shows a diagram of the cost structure for Czech Republic including the components of the fixed cost.

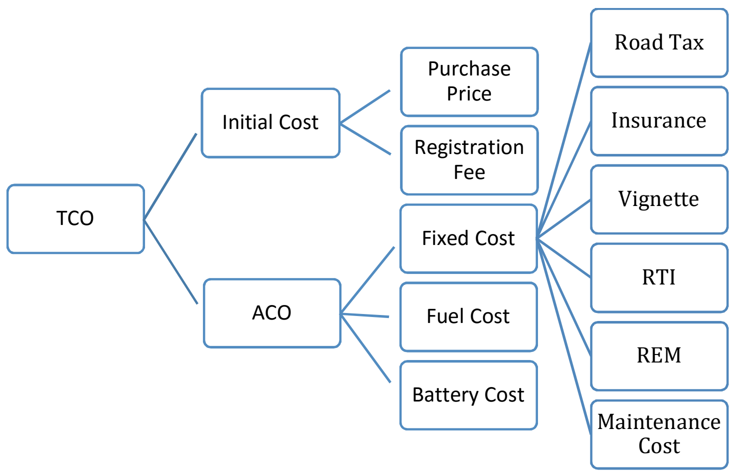


Figure 3.5. Diagram of Cost structure of the Czech Republic

The parameters used in the calculation of the TCO for the Czech Republic have been presented in table 3.5. The inflation rate and average annual distance travelled was calculated by taking the average of the available statistical data, for a certain number of years. The electricity prices, gasoline prices, and the exchange rates used are that of year 2016.

Inflation rate (%)	1.329
Exchange Rate (CZK/€)	27.039
Average Annual Distance Travelled (km)	9787.85
Electricity Price (Euros/kWh)	0.1293
Gasoline Price (Euros/l)	1.0629
VAT (%)	21

Table 3.5. Parameters used for the calculation of TCO for the Czech Republic. (MoF-CZ, 2016), (CNB, 2016), (ODYSSEE Database, 2014), (Eurostat, 2016), (CSO, 2016), (ACEA TAX GUIDE, 2016)

The costs, in the Czech Republic, of owning a Nissan LEAF and Nissan Pulsar are given in tables 3.5 and 3.6 respectively.

Nissan LEAF Costs in the Czech Republic	
Initial Cost	Euros
Purchase Price	26998,04
Registration fee	29,59
Annual Fixed Costs	Euros
Road Tax	0
Insurance	122,75
Vignette	55.485
RTI	14,65
REM	0
Maintenance Costs	0

Table 3.5. Nissan LEAF Costs in the Czech Republic (ACEA TAX GUIDE, 2016)

Nissan Pulsar Costs in the Czech Republic	
Initial Cost	Euros
Purchase Price	17419,28
Registration Fee	29,59
Annual Fixed Costs	Euros
Road Tax	66,57
Insurance	153,93
Vignette	55.485
RTI	14,65
REM	8,73
Maintenance Costs	82,47

Table 3.6. Nissan Pulsar Costs in the Czech Republic (ACEA TAX GUIDE, 2016)

The VAT in Czech Republic is 21% (ACEA, 2016). Hence, the VAT excluded yearly battery prices were calculated from the forecasted battery prices and are given in table 3.2. The TCO model, for the Czech Republic, only uses battery prices for years 2020 and 2025 because the lifetime of the battery is given as 5 years or 100000 km. Table 3.9 shows the battery prices including VAT for the year 2020 and 2025 for Czech Republic.

Scenario	2020 (€/kWh)	2025 (€/kWh)
Best	302.9238	262.7661
Base	340.9351	297.492
Worst	376.9954	329.11

Table 3.7. Battery Prices Including 21% VAT for Czech Republic
(Own calculation using data from (Plötz, Gnann, Kühn, & Wietschel, 2013), and the (ACEA TAX GUIDE, 2016))

In the case of the Czech Republic, we notice that the average distance travelled equals 100000 kilometres in approximately 10 years. Hence, TCO was calculated for the scenario where battery is changed every 5 years and where battery is changed every 100000 kilometres.

3.2.2 TCO Model for Austria

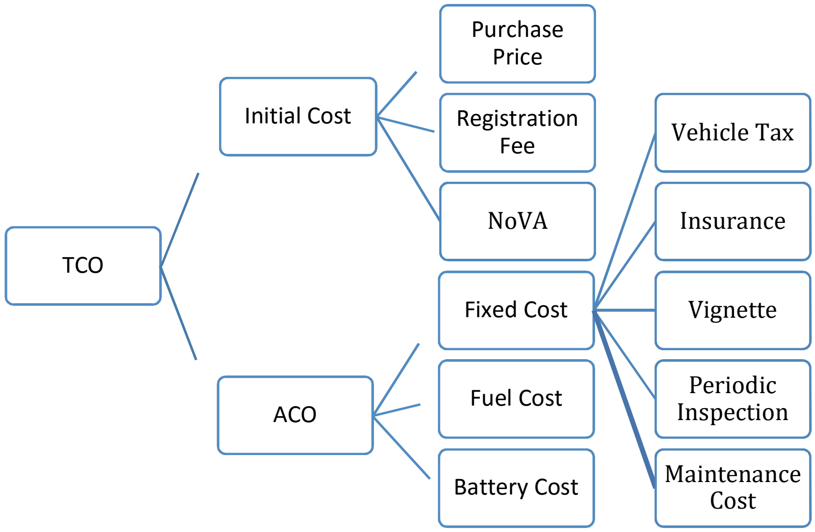


Figure 3.6. Diagram of Cost structure of Austria

Inflation rate (%)	2.0063
Average Annual Distance Travelled (km)	14453.33
Electricity Price (Euros/kWh)	0.1925
Gasoline Price (Euros/l)	1.16
VAT (%)	20

Table 3.10. Parameters used for the calculation of TCO for Austria (2016 European Union VAT rates , 2016) (GlobalPetrolPrices, 2016) (Statistik Austria, kein Datum) (WKO (Wirtschaftskammer Österreich), 2016) (Eurostat, 2016)

Nissan LEAF Costs in Austria	
Initial Cost	Euros
Purchase Price	28806
Registration fee	188
NoVA	0
Annual Fixed Costs	Euros
Vehicle Tax	0
Insurance	685
Vignette	85,7
Periodic Inspection	54,97
Maintenance Cost	0

Table 3.11. Nissan LEAF Costs in Austria (NISSAN Leaf, 2016) (Asfinag, 2016) (Durchblicker, 2016) (ÖAMTC, 2016)

Nissan Pulsar Costs in Austria	
Initial Cost	Euros
Purchase Price including NoVA	23518
Registration Fee	188
Annual Fixed Costs	Euros
Vehicle Tax	483,12
Insurance	615,52
Vignette	85,7
Periodic Inspection	54,97
Maintenance Costs	940,8

Table 3.12. Nissan Pulsar Costs in Austria (ÖAMTC, 2016) (Asfinag, 2016) (Durchblicker, 2016) (VAV Versicherung, 2016) (NISSAN Pulsar, 2016)

Scenario	2020 (€/kWh)	2022(€/kWh)	2025 (€/kWh)	2029 (€/kWh)
Best	300.4203	290.4679	281.7127	273.9234
Base	338.1175	327.3612	317.8940	309.4665
Worst	373.8798	362.0212	351.5852	342.2965

Table 3.13. Battery Prices Including 20% VAT for Austria (own calculation using data from Patrick Plötz, 2013, and the ACEA TAX Guide, 2016)

NoVA

In Austria you not only pay for the purchase price but also the standardised consumption tax called NoVA. The cost for standardised consumption tax depends on the car consumption and on the different engine capacity. The highest payment for NoVA makes 16 percentage of the original price and you have to pay it directly to the vehicle dealer who pays it to the tax office. Those who register their vehicles for the first time in Austria have to pay.

You have to pay NoVA additional to 20% the value added tax (VAT). So it should compensate the old increased VAT from about 32%. (Just Landed, kein Datum)

Vehicle examination

Before licensing you have to check if your car has road safety, industrial safety, environmental compatibility and many more to get a licence sticker called “Pickerl”.
The intervals for inspection appointment are three years after the first licensing, two years after the first inspection and then you have to do a check every year. In this period you have one month before and four months after the date of the first authorisation for the next vehicle inspection.
The costs are between 25€ and 70€ and depend on the car label, the garage and if you use a petrol or diesel engine.

Liability insurance

It is regulated by law to take out a liability insurance in Austria. After your insurance cover starts you get an insurance policy. For example the Nissan Leaf is classified as type 17 and you have to pay approximately 155€ per year.
(Durchblicker, 2016)

Registration of cars

With your motor insurance policy your car will get registered from the insurance company. A new registration cost in Austria 170€ and if you need a new license plate you have to pay 18€ extra.
(Bundeskanzleramt_Kfz Zulassung, kein Datum)

In Austria tax exemptions are granted for E-cars. These vehicles are exempt from the standard fuel consumption tax (NoVA) and Petroleum tax. Only EVs are free for engine-related insurance tax vehicles. Compared to conventional cars you have low maintenance costs and subsidies are available.
Since 2016 companies "get a VAT refund and furthermore the private use of electric company vehicles will not count as remuneration in kind." Companies have about 50% registration of new cars.
The government tries to increase the number of EVs up to 5% till 2020.
(Energiemagazin.at, kein Datum) (Bundesministerium für Finanzen, kein Datum; Bundesministerium für Finanzen_Normverbrauchsabgabe, kein Datum) (Climate and Energy Fund, 2015)
(STATISTIK AUSTRIA, 2016)
Since this year electric vehicles will be tax deductible up to a net value of 40,000€ per car. Only EVs are free for engine-related insurance tax.
(Bundesministerium für Finanzen_Normverbrauchsabgabe, kein Datum)

4 Results

4.1 Czech Republic

The TCO model used provided the results given in tables 4.1 and 4.2. The TCO was calculated for the three different battery price scenarios as well as for the two different battery change scenarios. Table 4.1 gives the TCO for the case where the battery of the EV is changed every five years, and table 4.2 provides the TCO for the case where battery is changed after 100000 kilometres.

TCO [€/km] - 15 year ownership, Battery Lifetime = 5 years			
Battery Scenario	Nissan LEAF - EV	Nissan Pulsar - ICEV	Difference
Best Case	0.300221	0.217167	0.083054
Base Case	0.310506	0.217167	0.093338
Worst Case	0.320085	0.217167	0.102917

Table 4.1. TCO of EV and ICEV for Czech Republic, Battery Lifetime = 5 years

TCO [€/km] - 15 year ownership, Battery Lifetime = 100000km (~10 years)			
Battery Scenario	Nissan LEAF - EV	Nissan Pulsar - ICEV	Difference
Best Case	0.255371	0.217167	0.038204
Base Case	0.260027	0.217167	0.04286
Worst Case	0.261909	0.217167	0.044742

Table 4.2. TCO of EV and ICEV for Czech Republic, Battery Lifetime = 100000 kilometres

The results obtained show that ICEV has a lower TCO for all three battery price scenarios as well as for the two battery change scenarios. Figure 4.1 shows this comparison graphically. The difference between TCO of ICEV and EV is lower for the scenario where battery is changed after 100000 kilometres.

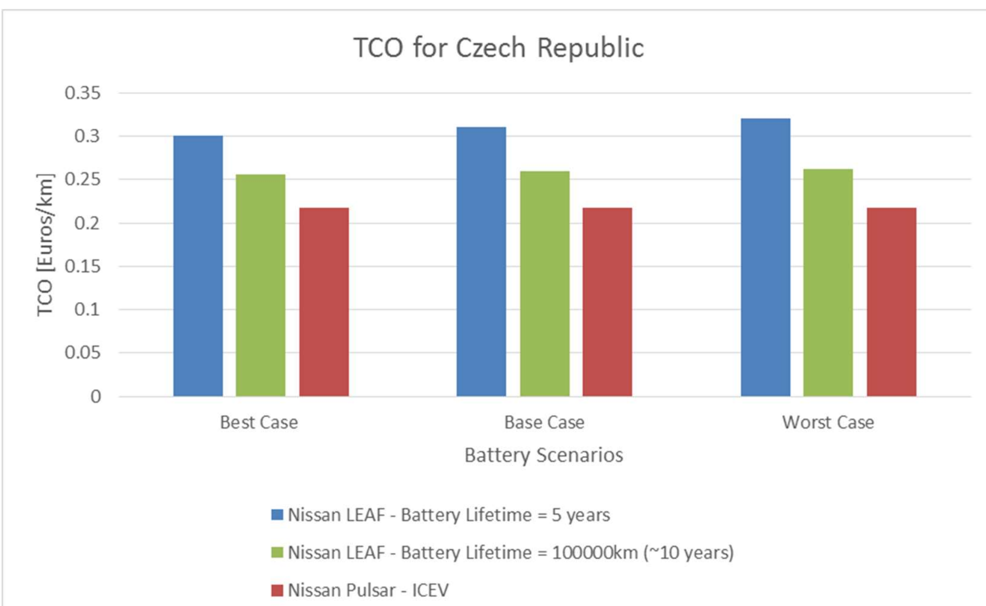


Figure 4.1. TCO of EV and ICEV for Czech Republic

4.2 Austria

The current TCO model was calculated for two different battery changed scenarios (5 years & 100000 km) and also for three different battery price scenarios. These calculations were made for the two cars Nissan LEAF and Nissan Pulsar.

TCO [€/km] - 15 year ownership, Battery Lifetime = 5 years			
Battery Scenario	Nissan LEAF - EV	Nissan Pulsar - ICEV	Difference
Best Case	0.271880	0.327830	0.05595
Base Case	0.278787	0.327830	0.049043
Worst Case	0.285221	0.327830	0.042609

Table 4.3. TCO of EV and ICEV for Austria, Battery Lifetime = 5 years

TCO [€/km] - 15 year ownership, Battery Lifetime = 100000km (~7 years)			
Battery Scenario	Nissan LEAF - EV	Nissan Pulsar - ICEV	Difference
Best Case	0.265388	0.327830	0.062442
Base Case	0.271619	0.327830	0.056211
Worst Case	0.277306	0.327830	0.050524

Table 4.4. TCO of EV and ICEV for Austria, Battery Lifetime = 100000 kilometres

In figure 4.2 shows that ICEV has a higher TCO for all three battery price scenarios. Even in the worst case scenario the TCO of Nissan LEAF is cheaper than the TCO of Nissan Pulsar. The difference between 5 year and 100000km battery change is not that much.

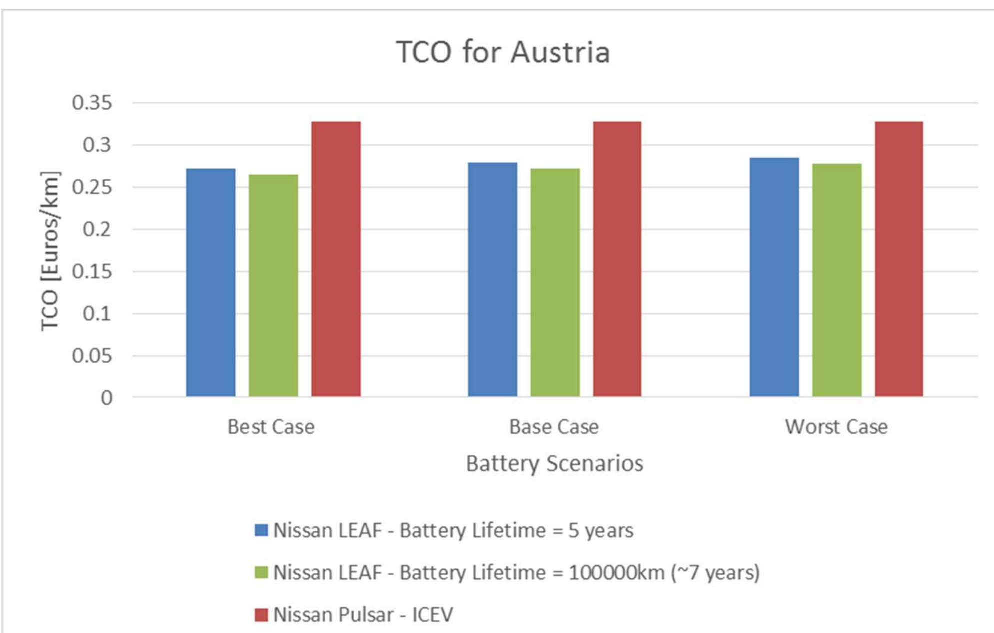


Figure 4.2. TCO of EV and ICEV for Austria

5 Sensitivity and Scenario Analysis

5.1 Sensitivity Analysis

In order to understand the effect of discount rates on the TCO of the car ownership, it is crucial to conduct a sensitivity analysis. It is apparent that an increase in the discount rate would cause the TCO to decrease. However, the exact effect of changing discount rates for the countries being studied might be different. The sensitivity analysis for the Czech Republic and Austria has been provided in the subsequent sections.

The sensitivity analysis has been conducted for the base case battery price scenario.

5.1.1 Czech Republic

The TCO, in the Czech Republic, of both vehicles decreases as the discount rate is increased. This is shown in figure 5.1. The graph suggests that it is an almost predictable decrease. Furthermore, in the case of the Czech Republic, the difference in the TCO of ICEVs and EVs is not highly dependent on the discount rate. On the other hand, we will notice a decrease in the difference between the TCO of ICEVs and EVs in Austria when discount rates are increased. The reason behind this could be the higher IC of purchasing an EV in the Czech Republic.

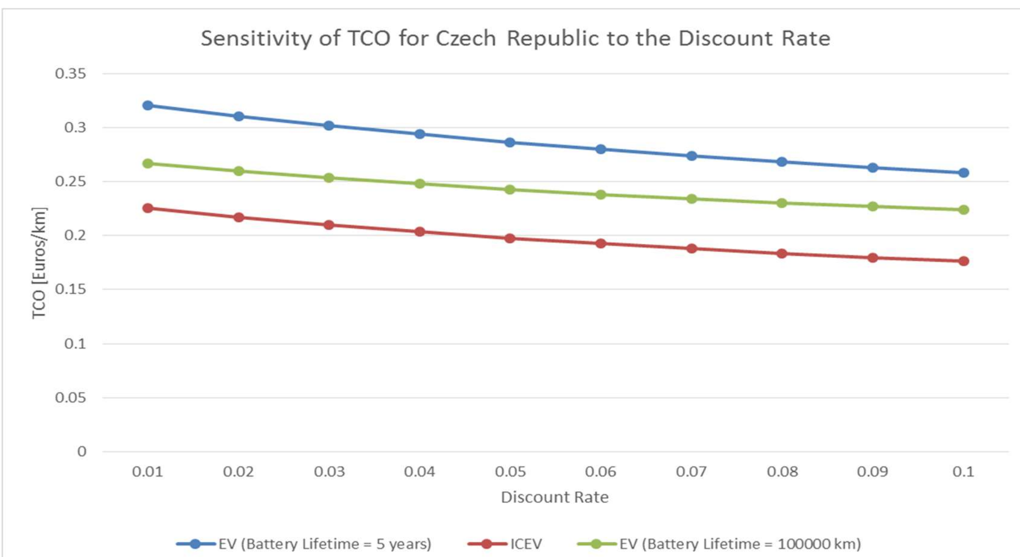


Figure 5.1. Sensitivity of TCO to the discount rate for Czech Republic

5.1.2 Austria

If the discount rate increase the TCO from EV and ICEV increase as well.
As you see in Austria the ICEV depends more on the discount rate than the EV.

The discount rate describes the further costs. The annual costs of the ICEV are higher than the costs of the EV. That's the reason why the discount rate reduction is bigger for the ICEV than for the EV.

The additionally costs are lower for the ICEV than the EV.

In this TCO scenario we show only the 5 years battery lifetime, because there is no much difference to the 100000km scenario.

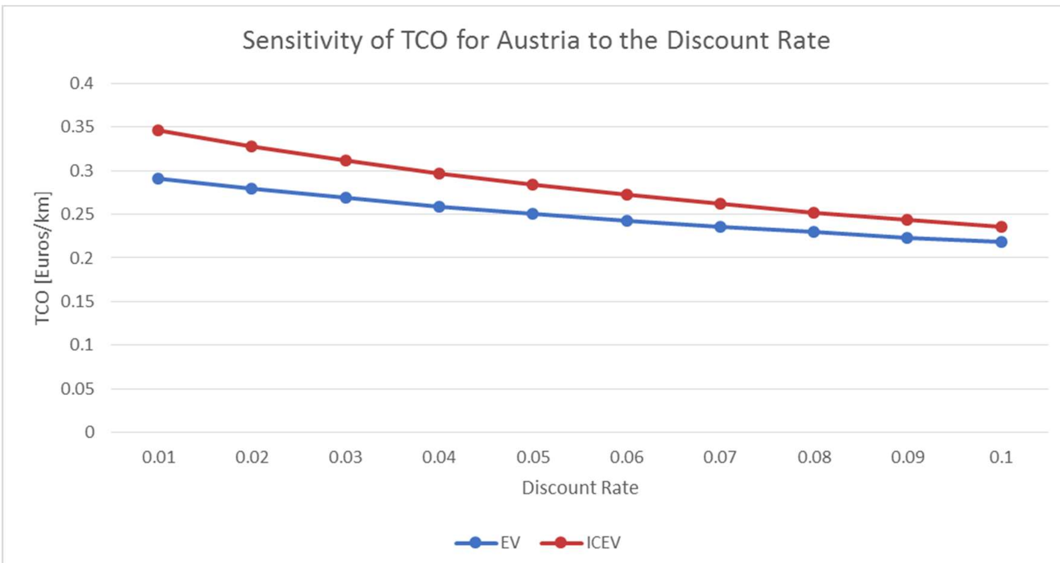


Figure 5.2. Sensitivity of TCO to the discount rate for Austria

5.2 Scenario Analysis

There are certain tools, which can be utilized to encourage consumers to purchase EVs, or discourage them from purchasing ICEVs. This study analyses the effect of two such cost effecting incentives. The introduction of a government subsidy on the purchase of an EV and the taxing of carbon emissions of ICEVs. Since both, the Czech Republic and Austria, do not offer such incentives or taxes it would be noteworthy to investigate their effect on the TCO.

The subsidizing of EVs would result in a decrease in the consumer's IC, resulting in a decreased TCO of EVs. On the other hand, the introduction of carbon emission tax on ICEVs would cause an increase in their ACO, further resulting in an increase in the TCO of ICEVs.

The sensitivity analysis has been conducted for the base case battery price scenario.

5.2.1 Czech Republic

5.2.1.1 Subsidizing Electric Vehicles

The effect of a government subsidy on the purchase of EVs in the Czech Republic has been presented in figure 5.3. The TCO of ICEV in the Czech Republic was calculated to be 0.217 Euros/km. A comparison of the TCO of ICEV with the subsidized TCO of EVs given in figure 5.3, shows that even at a subsidy of 6000 Euros, the TCO of the EV, when battery is changed after 100000 km, would be 0.219 Euros/km, which is still slightly higher than that of the ICEV.

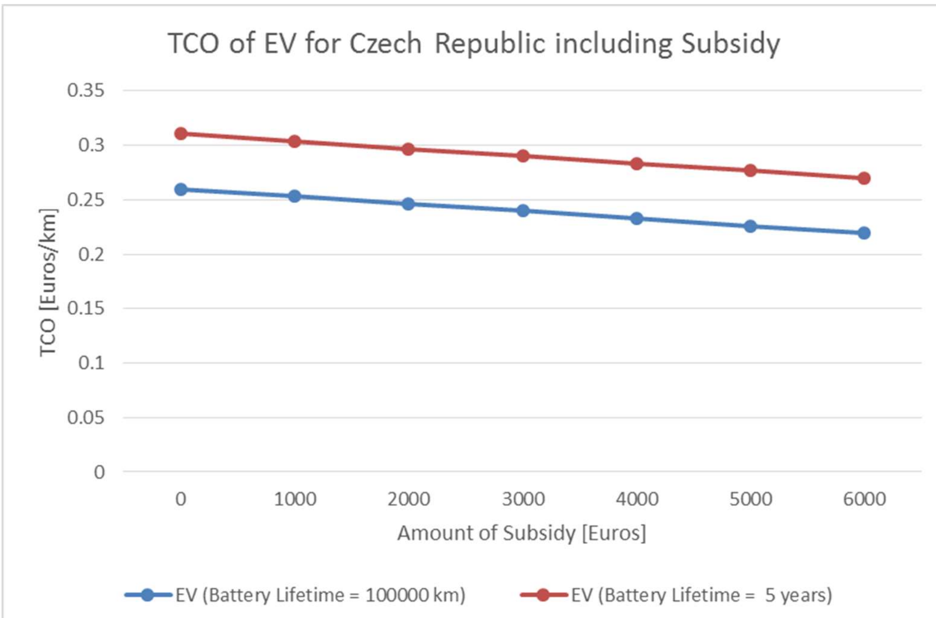


Figure 5.3. TCO of EV for Czech Republic including the influence of subsidies

5.2.1.2 Introduction of Carbon Tax

The results of the previous scenario analysis confirmed that it is vital to introduce a carbon tax along with the subsidy, to increase the appeal of EVs in the market.

Figure 5.4 shows the impact of varying values of carbon emission tax on the TCO of the ICEV in the Czech Republic. The general trend suggests that the TCO of ICEV would increase when carbon tax is increased. In the case when the carbon tax is 0.05 Euros/kg of carbon dioxide released, the TCO of ICEV in the Czech Republic become 0.223 Euros/km.

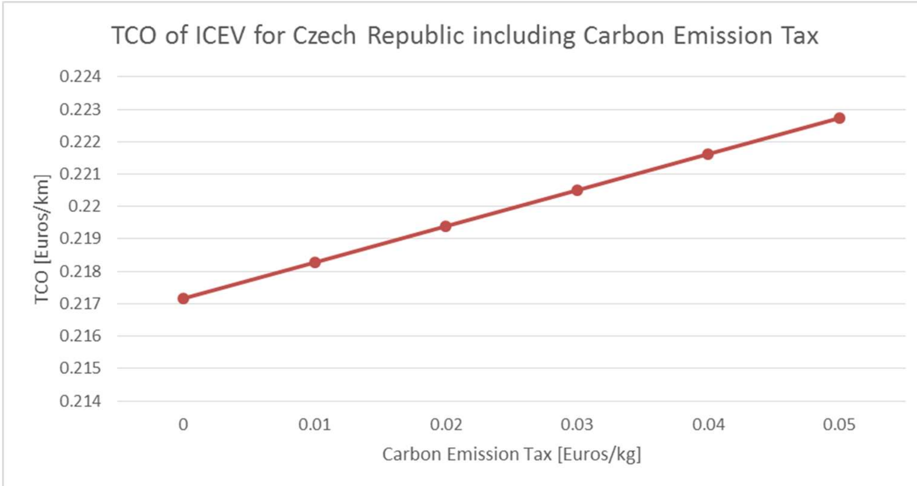


Figure 5.4. TCO of ICEV for Czech Republic including the influence of Carbon Emission Tax

5.2.2 Austria

5.2.2.1 Subsidizing Electric Vehicles

The Austrian government has a huge influence on the TCO costs. When the subsidies increase the TCO decrease. Therefore there is a higher chance that more people will by new Electric Vehicle instead of a new ICEV. But people in Austria have to consider that the subsidies are variable in the different parts of Austria.

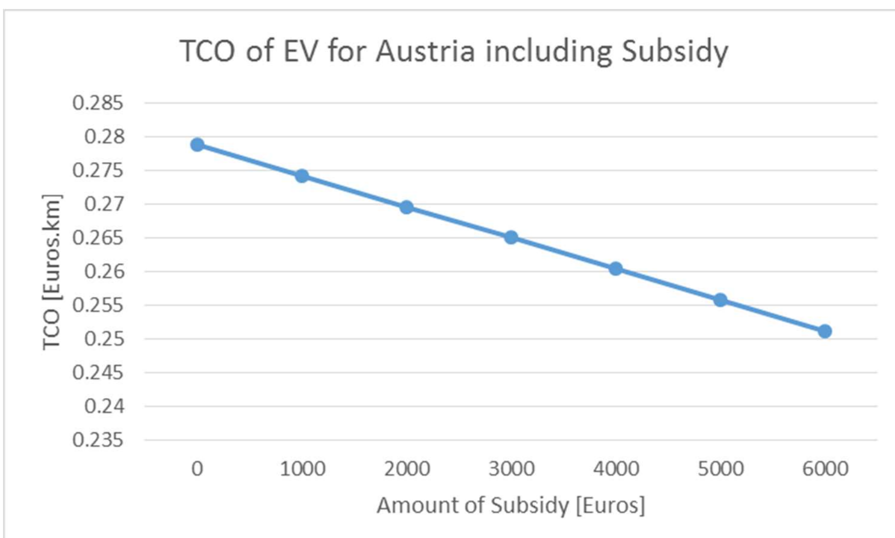


Figure 5.5. TCO of EV for Austria including the influence of subsidies

5.2.2.2 Introduction of Carbon Tax

The government has not only influence on the subsidies but also on the Carbon Tax. Figure 5.6 shows an increasing trend of the TCO when the carbon tax increase. So in Austria for example if the carbon tax is 0.05 Euros/km the TCO of ICEV is 0.334 Euros/km.

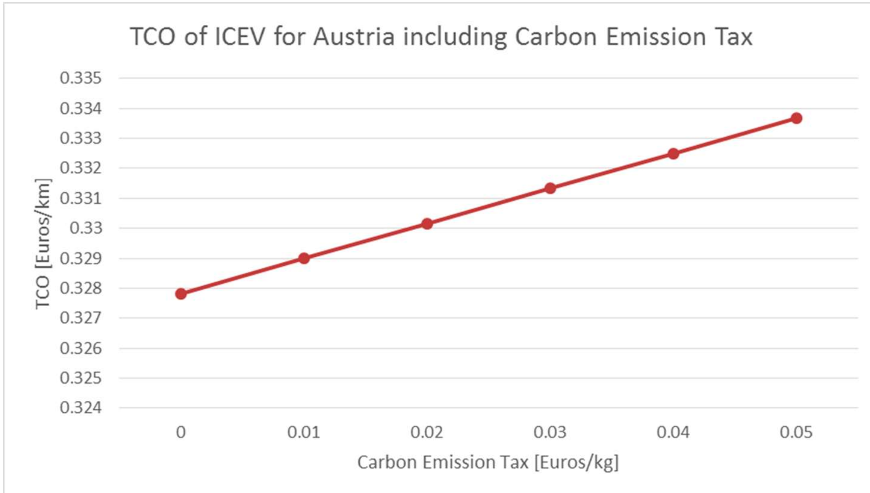


Figure 5.6. TCO of ICEV for Austria including the influence of Carbon Emission Tax

In the end with these two factors the government has the most influence on the purchase behaviour if someone buys an EV or ICEV.

5.2.2.3 Future of Electric Vehicles

If we have 100% EV we will have only approximately 16% more electricity consumption. (Climate and Energy Fund, 2015)
So there is a big potential to use.

When we use price signals and official regulatory procedures we can reduce 1,2 million tons till 2030 in road transport by using EVs.

The **business-as-usual scenario (BAU)** shows us that we will use 886.000 EVs (BEV & PHEV) in Austria till 2030.
In terms of CO2 emissions the **elector mobility+ scenarios (EM+)** drawn up at the European level by adjustment the NoVA, increased fuel tax and a expansion of the recharging infrastructure in Austria.
We can reduce the CO2 emission by using BAU scenario up to 1 million tons and in EM+ Scenario 1,2 million tons. (DEFINE - Development of an Evaluation Framework for the Introduction of Electromobility, 2014)

EVs are more Sustainable when you use renewable energy. The technology has also a high potential to reduce the noise and the air pollutant emissions.

Year	2016	2017	2018	2019	2020
Forecast of stock electro vehicles (EV & PHEV)	38.224	66.022	104.100	152.874	209.333
Registrations of used passenger cars (EV & PHEV)	0,75%	1,28%	1,99%	2,89%	3,91%
Actual registrations each year EV & PHEV	17.463	27.797	38.079	48.773	56.459
Registrations of new passenger cars (EV & PHEV)	5,40 %	8,49 %	11,50 %	14,55 %	16,65 %

Table 5.1 Austria electro mobility scenario till 2020 (Pötscher, Winter, & Lichtblau)

Table 5.1 considers an overview of an electro mobility scenario for EVs and PHEVs till 2020.
To create a scenario till 2050 it's hard to estimate the change of the automotive market on the one hand and otherwise is difficult to foresee the technical progress over such a long time.
Therefore the transport sector must be free from CO2-emissions till 2050.
The development of the fleet depends on the crude oil price, taxation of the vehicles, electricity, fuels and many more.
To replace all cars by BEVs and PHEVs under favourable conditions and effective climate policy will take till 2075.

Generally the CO2 emission for car traffic will be 20% reduced for ICE until 2050 by reason of efficiency.
If we use more electro mobility vehicle in public sector the trend will be changed from fossil fuels towards to electrical energy.
(Pötscher, Winter, & Lichtblau)

6 Conclusion

People are very excited of EVs, but the demand is quite low. Some reasons of limited demand are actually low range, infrastructure, supply of EVs, higher purchase costs and missing incentives for purchase. The government in Austria changed the law for 2016 to increase the market share of EVs.

The current components of electric cars should get cheaper and will be enhanced in the future. The actually battery size on the market should be enough for a car with only one charging station at the firm.

One of the biggest price effect has the battery due to the fact that it is the most expensive part of an EV. If the battery price is getting cheaper in the future, EVs are getting more attractive. This factor can reduce the gap between more expensive electric vehicles and ICEVs. This is one of the reasons to change the new registration from PHEVs to EVs.

The most successful EV markets in Europe provide more than one incentive as we can see in Norway or Netherlands.

Raising tax levels for ICEVs would be necessary for electric and eco-friendly cars.

Another main important factor are the investments in charging infrastructure. If we don't have an adequate infrastructure, we can't use EVs and no one will by an electric car.

As we see in the results, the government has the highest influence of the TCO. The TCO difference between Czech Republic and Austria are that the TCO of ICEVs are cheaper in Czech Republic than in Austria compared to EVs. This is one of the reasons, why EVs are more common in Austria than in Czech Republic.

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