Modeling of future market potential for electric vehicles in Sweden

Master's thesis within the Sustainable Energy Systems programme

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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS

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Abstract

The personal transport sector of today is dominated by fossil fuel vehicles such as diesel and gasoline cars. An option to decrease the carbon emissions from the transport sector could be to increase the share of the electric vehicles sold on the market.

In this study, the future market potentials for battery electric vehicles (BEVs) and plug-in hybrids (PHEVs) is evaluated by creating a model based on a database of driving patterns of cars in southwestern Sweden. The model is developed in Matlab and is based on a cost minimization approach, where each driver is assumed to buy the car with the lowest total cost of ownership. The possibility of driving using electricity is evaluated by making battery simulations based on the driving pattern of each user. The model forecasts the market of BEVs, PHEVs, diesel cars and gasoline cars twelve years into the future based on different oil price developments and charging infrastructures.

Several additional cases have been created where different policies and prerequisite have been studied such as increased subsidies for electric vehicles, increased fuel tax for conventional fuel and increased battery capacity.

The market share for electric vehicles twelve years from now is estimated to be between 2.3% when a low oil price and small charging opportunities are assumed, to 13.1% for a scenario of a high oil price and greater charging opportunities. These results are based on the same fuel tax and policies toward electric vehicles as are implemented today.

Our results indicate that for the different future oil prices and charging infrastructures assumed in this study, charging infrastructure has the largest effect on the electric car market. In the model policies aimed towards reducing the gap between investment cost of electric vehicles and conventional vehicles have been more effective than policies towards increasing the running cost of conventional vehicles.

Keywords: Electric vehicles, modeling, battery simulation, BEV future market potential, PHEV future market potential, cost minimization, Sweden

Acronyms

CO_2	Carbon dioxide
EV	Electric vehicle
PHEV	Plug-in electric vehicle
BEV	Battery electric vehicle
SCMDD	Swedish car movement data project
IEA	International Energy Agency

1. Introduction

1.1 Background

Global warming and increasing emissions of carbon dioxide is a large problem for both current and future generations. In 2012, 33% of Sweden's emissions of greenhouse gases originated from the transport sector, of which around half came from personal cars, light duty trucks, motorcycles and mopeds (Trafikverket, 2014). According to the Swedish Environmental Protection Agency, the total emissions from the Swedish personal car fleet were 10753 kton CO_2-equivalents in 2013. The emissions have been slowly decreasing since 2007 (Naturvårdsverket, 2014). This is explained by a decreasing growth of new personal vehicles, more fuel-efficient vehicles and an increased number of biofuel vehicles. However, if the diffusion of electric vehicles on the personal car market would increase the emissions from the personal car fleet would decrease at a faster rate.

There are many ways to reduce carbon emissions from personal transports. Many of these are non-technical policies such as road pricing, congestion charging and speed limits. The problem with these solutions is that they have a direct effect on the life style of people and would therefore possibly be hard to implement. A change from conventional vehicles fueled by gasoline or diesel to electric vehicles would be an option to reduce the environmental impact of the personal transport sector, without heavily interfering in the life style of people. The transport sector of today is reliant on petroleum, which is a fossil resource and thus other types of fuel have to be developed to reach a sustainable transport sector (Kahn Ribeiro, 2007). Electric vehicles (EV), such as battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) have the potential of reducing greenhouse gas emissions from the transport sector, especially in Sweden where a large share of both current and future electricity production will be carbon dioxide neutral (Svensk Energi, 2012).

However, electric vehicles are much more expensive than conventional vehicles, and there is not a significant number of EVs on Swedish roads today. According to Statistics Sweden, only 0.3% of the vehicles sold in February 2014 were BEVs and 0.6% were PHEVs (Statistiska centralbyrån, 2015). However, electric vehicles will get cheaper in the future when the technology matures. Its future market diffusion depends on several different factors such as battery technology, oil and electricity prices and charging infrastructure (Gnann et al., 2015).

1.2 Aim of the work

The aim of the study is to develop a Matlab model that evaluates the future market diffusion of BEVs and PHEVs in Sweden. The model will give results from today and for every year up to twelve years into the future. The model will be based on a database providing GPS loggings of 714 private cars in western Sweden between 2009 and 2012 (Karlsson, 2013). A total of 714 car profiles were logged but only 429 of these were tracked in a period long enough to be considered relevant for this study. Cost of ownership calculations based on running costs, investment costs, feasibility of BEVs and the electric driving share of PHEVs will be used to determine the most cost optimal vehicle for each driver. Finally, several cases will be created to test different scenarios and market policies.

The study aims to answer questions such as:

- How will the future market potential be for electric vehicles?
- How large share of car drivers could change to a BEV without changing their driving patterns?

A similar study has been performed in Germany (Gnann et al., 2014) where the future development of electric commercial passenger cars have been estimated based on German scenarios. Data from self reported driving of cars for one week have been used to calculate the viability of electric vehicles as well as total cost of ownership for several different vehicle types. There have been similar models made before but no one has been made for Swedish conditions.

1.3 Limitations

Due to time limitations, the vehicle types considered in the cost of ownership calculations are PHEVs, BEVs, diesel cars and gasoline cars. Other vehicles such as range extended electric vehicles, fuel cell vehicles and bio-fueled vehicles will not be included in this work.

Since the GPS logging only includes private vehicles, vehicle used for other purposes, such as company cars, will not be taken into consideration. The logging comes from cars exclusively in the Västra Götaland region in western Sweden and this data is assumed to be a good representation of Sweden as a whole. Because no car specific details are available, the impacts of for example car brands will not be considered. The exception is information about car sizes, where the cars will be divided into three groups. In the study it is assumed that users are investing in vehicles based on a cost minimization principle. No other factors such as willingness to pay more, brand loyalty or status from bought vehicle will be included in the model. In the study the model will be used only for making calculations twelve years into the future.

2. Methodology

2.1 Model

The model that is used to evaluate the market potential for electric vehicles is divided into three parts. The first part is a battery simulation that evaluates what users that can invest in a BEV without having to change their driving pattern. The battery simulation also evaluates how large proportion of the total driving during one year that could be driven on electricity if the user would invest in a PHEV. The second part is based on equations that calculate the total cost for owning a vehicle for the four vehicle types in the model (BEVs, PHEVs, gasoline vehicles and diesel vehicles) for all users in the database. The third part is emission calculations that evaluate how large emissions that are associated with the production and driving of the vehicles. The model will also give the average distance travelled during a year for the four different vehicle types. This data is interesting because it gives a hint about how much a user has to commute each year to make the different vehicle types competitive. An illustration of the model is shown in Figure 1.

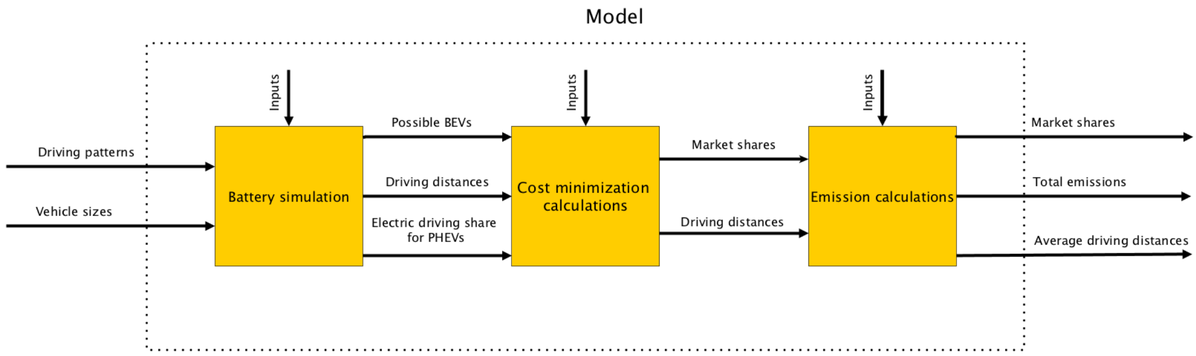

Figure 1: An illustration of the model. The model can be divided into three parts: Battery simulation, cost minimization and emission calculations. Out from inputs of driving patterns and vehicle sizes, the model calculates the market share, total emissions and average driving distances.

2.1.1 Cost minimization

The cost minimization is based on a total ownership cost from investment to resale of the vehicle. It will be assumed that the users will use their vehicle for eight years before selling it on the used car market. What type of vehicle that minimize the cost for a particular owner is different in the model based upon how much they use the vehicle, the nature of the driving pattern and how often and how long the stop times between trips are. The total cost of ownership will be divided into two different equations: one for calculating the capital costs and one for calculating the running cost. The model will calculate the market share for the four vehicle types (BEV, PHEV, gasoline vehicles and diesel vehicles) that will be sold for each year for the coming next twelve years. Some parameters will change over time while others will remain constant.

To calculate the capital expenditure (C_i^{cap}) the discounted cash-flow method is used as can be seen in Equation 1.

$$C_i^{cap} = P_i - S_i - \frac{SP_i}{(1+r)^t} \quad (1)$$

The first tem P_i is the purchasing cost of vehicle i and S_i is the subsidy (sw. miljöbilspremie), when purchasing an electric vehicle (both BEV and PHEV). SP_i is the resale value of the vehicle that has to be divided by a time factor that takes the present value of money into consideration. The time factor consists of two parameters: r is the interest rate and t is the time horizon or the amount of time that the driver will own the vehicle before selling it. All of the parameters in the capital expenditure will remain constant except for the investment cost of electric vehicles. The investment cost for electric vehicles are divided into two different parts: chassi and battery. The investment cost for the chassi is assumed to remain constant for all of the twelve years while the investment cost for the battery is assumed to decrease for each year (Nykvist, Nilsson, 2014). The battery part of the total investment cost is larger for BEVs than for PHEVs due to the larger batteries of the BEVs. That also leads to a larger decrease in price for BEVs compared to PHEVS. To calculate the running cost for user i Equation 2 is used.

$$C_i^{op} = \sum_{t=0}^{t=t} VKT_i * \frac{(d_e c_e k_e + (1-d_e) c_c k_c)}{(1+r)^t} \quad (2)$$

VKT is the annual kilometers traveled by device i. The driving distances from the database are logged during different time periods and have to be normalized for one year in the model. The first part inside the brackets are the cost for electric driving where d_e is the electric driving share, c_e is the consumption of electricity in kWh/km and k_e is the cost of electricity in SEK/kWh. The second part inside the bracket is the cost of conventional driving where c_c is the consumption of diesel or gasoline in l/km and k_c is the cost of fuel for diesel or gasoline in SEK/l. The electric driving share will be 100% for the BEVs, between 0 and 100% for the PHEVs and 0% for the conventional fuel vehicles. To calculate what users that can drive with a BEV and how large proportion of the distance that can be driven with electricity a battery simulation has to be done.

In the running cost equation the electricity price will remain constant while the conventional fuel change each year. It is also assumed that the price of gasoline and diesel will be proportional to the oil price. Even if the oil price will change for each year, it is assumed that the owner will invest based on the oil price of the year of purchase. The reason behind this is that the owner of the vehicle cannot know how the development of the fuel prices will be and have to make his or hers decision based on the present fuel price. However, the conventional fuel price will follow the oil price development for each year for the new owners.

Finally the cost minimization function will be:

$$\min (C_i^{cap} + C_i^{op}) \quad (3)$$

From Equation 3 the type of vehicle that will minimize the total cost for each owner for each of the twelve years is calculated. By dividing the total number of a particular vehicle type that has the lowest total cost by the total number of users in the database the market share for that particular vehicle type is calculated. This will be done for each of the twelve years.

2.1.2 Battery simulation

In the battery simulation, data of driving habits (including driving distances and stopping times) for 429 vehicles from the Swedish car moment data project (SCMDD) is simulated as BEVs, PHEVs and conventional fuel vehicle (both diesel and gasoline) in Matlab. From the simulation it can be evaluated how many drivers that can exchange their vehicles to a BEV taking battery limitations into consideration. The battery simulation will also show how large the electric driving share that could be accomplished with a PHEV is. The 429 vehicles are divided into three groups depending on the total weight of the vehicles: small, medium and large. Depending on what category the vehicles belong to, the vehicles will get different values for parameters such as investment price, fuel consumption, battery size and resale value. The model is based on a battery simulation using the status of battery calculations shown below. All parameters in the battery simulation remain constant during the whole time horizon. The battery simulation for year 1 is the same as the battery simulation during year 12.

$$C(t+1) = \begin{cases} C(t) - d_{\Delta t} * c_e & for \quad d_{\Delta t} > 0 \\ \min\{C(t) + \Delta t * P_{charge}, C_{max}\} & \quad\quad d_{\Delta t} = 0 \end{cases} \quad (4)$$

$$C_{max} = C_{nominal} * DOD \quad (5)$$

The upper part of Equation 4 is used to determine the electricity consumption during electric driving while the bottom part used to determine the amount of power charged when the vehicle is parked. C(t) is the amount of useable energy left in the battery in kWh at time t. At t=0 C(t) = C_{max}, where C_{max} is the maximum useable capacity of the battery in kWh. C_{max} is calculated in Equation 5 by multiplying the nominal maximum capacity of the battery, $C_{nominal}$, with the depth of discharge for the battery DOD. In this paper the depth of discharge is a constant that explains the fraction of the total capacity of the battery that can be used. $d_{\Delta t}$ is the distance travelled between t and Δ_t in km and c_e is the consumption of electricity in kWh/km. P_{charge} describes the amount of power charged at the location where the car is parked in kW. In the model it will be assumed that charging is only possible when the stop time is larger or equal to four hours when the battery can be charged at both the working place and at home and ten hours when it is assumed that the vehicle only can be charged at home. If the stop time is smaller than four hours in the first case or ten hours in the second case P_{charge} = 0. If C(t) at any time goes below zero conventional fuel has to be used for PHEV to power the vehicle and the car will not be able to be exchanged to a BEV.

2.1.3 Emission calculations

In this part the CO_2-emissions from the added car fleet in Sweden is calculated for each year, see Equation 6. The emissions include the production of the vehicle as well as the emissions from travelling.

$$E_{CO2} = N * \sum_{i=1}^{i=429} \frac{EPr_{CO2} + Yr * VKT_i\,(d_e c_e e_{eco2} + (1-d_e) c_c e_{cco2})}{Yr * 429} \quad (6)$$

For this calculation N is the number of cars that are sold for each year in Sweden. EPr_{CO2} is the emissions associated with the particular vehicle type. VKT_i is the annual distance traveled in km, d_e is the electric driving share, c_e is the consumption of electricity in kWh/km, e_{eco2} is the emissions from the electricity production in CO_2-eq/kWh based on average Nordic electricity mix, c_c is the fuel consumption in l/km and e_{eco2} is the emissions from the conventional fuel in g CO_2-eq/l.

Equation 6 will show how the total CO_2 -emissions from the added car fleet will be for each year. In this part it is assumed that the amount of cars that are sold each year will not change the next coming years. N will therefore remain constant for the twelve years. For this calculation it is also assumed that the CO_2-emissions from the production can be evenly distributed during the eight years that the user owns the vehicle.

2.2 Scenarios

The model will give four results depending on four different scenarios. The scenarios are used to give a span for the results depending on parameters that are assumed to have large influence on the results, but that also are hard to predict how they will be in the future. In this study these parameters are charging infrastructure and oil prices.

The scenarios will be called A, B C and D.

- Scenario A: Describes a future scenario with a low oil price and where there will be high possibilities to charge electric vehicles.

- Scenario B: Describes a future scenario with a high oil price and where there will be high possibilities to charge electric vehicles.

- Scenario C: Describes a future scenario with a low oil price and where there will be low possibilities to charge electric vehicles.

- Scenario D: Describes a future scenario with a high oil price and where there will be low possibilities to charge electric vehicles.

In the Results section, the graphs that are presenting the market shares of each vehicle type are organized as in Figure 2.

	Low oil price	High oil price
High charging possibilities	A	B
Low charging possibilities	C	D

Figure 2: A representation of the scenarios used in the model.

2.2.1 Charging infrastructure

Two different possibilities for charging the vehicles will be used in the scenarios. One represents high possibilities to charge the electric vehicles where the users can charge the vehicle at home as well as at the working place. This is simulated in the code for the model by assuming that electric vehicles need to have a stopping time of at least four hours if the battery will be charged at all. The low scenarios for charging infrastructure are scenarios where there only will be possibilities to charge electric vehicles at home. This is modeled in the code by instead using at least ten hours stopping time for the charging. The four and ten hours used in the study is taken from (Björnsson.,Karlsson, 2015).

2.2.2 Prediction of future gasoline and diesel prices

The diesel and gasoline prices in the model are based out of future oil price predictions made in world energy outlook 2014 (International Energy Agency, 2014). To obtain the gasoline and diesel prices an assumption has been made that the prices of processed fuels follows the price of raw oil. The International Energy Agency (IEA) crude oil import price in year 2013 was 106 dollars per barrel oil. This is used as the oil price for year 1. In the model there will be two different predictions for the development of the oil price until 2025. The two oil prices are based on a high and low oil price scenario. The increase or decrease in oil price is assumed to be linear until 2025 which is a close estimation of the prediction of the future oil prices made in World Energy Outlook 2014.

Three different scenarios are described in World Energy Outlook 2014: current policies scenario, new policies scenario and 450 ppm scenario. From these three, only two scenarios will be used: current policies scenario to describe a high future oil price scenario and 450 ppm to describe a low oil price scenario. The third scenario that is not used in the model is the New Policy Scenario that is the price prediction that World Energy outlook believes is the most reliable scenario. In this scenario the development of the oil price will be somewhere between the current policy scenario and the 450 ppm scenario.

The current policies scenarios describe a business as usual scenario where only the policies and measures that had been adopted as of mid-2014 are taken into consideration. It works as a baseline scenario of what will happen with the energy market if it will evolve without any new policy intervention. In this scenario the energy demand will grow with 1.5 % per year between 2012 and 2040. The IEA crude oil price import price will be 130 dollars per barrel in 2025. This is a smaller increase in energy demand compared to the last decades where the energy demand on average has increased with 2.1 % per year. The IEA crude oil import price in this scenario is higher compared to the 450 ppm scenario. The main reason for this is that because of fewer policies to reduce the oil demand, higher prices are needed to keep supply in line with the higher demand.

The 450 ppm scenario is based on measures that are necessary if the long term increase of global temperature is not to increase above 2 °C. It is an illustration of how radical changes will affect the energy prices. In this scenario the greenhouse gases in the atmosphere peaks at a level above 450 ppm in the middle of this century but the level of greenhouse gases stabilizes around 450 ppm after 2100. In this scenario extended subsidies for alternative vehicles are used to decrease the oil consumption in the transport sector. How large the subsidies will be in Sweden are however not stated but assumptions have been made that the subsidies of alternative vehicles in Sweden will have a negligible effect on the IEA crude import price and will therefore not be included in the model. The energy demand for the 450 ppm scenario grows on an average with 0.6 % per year between 2012 and 2040 and the peak oil will be reached around 2020. The IEA crude oil import prices will be 105 dollars per barrel by 2025.

2.3 Technical and economical parameters

In the model, several parameters have been estimated and used. Some properties are vehicle independent while others change based on the type and size of the considered vehicle. Several parameters that are hard to estimate have been examined further in different cases. The vehicle size independent data used is shown in Table 1.

Table 1: Non-vehicle size dependent parameters used in the model.

Parameter	**Value**	**Reference**
BEV depth of discharge	0.90	Gnann et al., 2014
PHEV depth of discharge	0.75	Gnann et al., 2014
Posession time [yrs]	8	Assumption
Interest rate	0.05	Gnann et al., 2014
Subsidy [SEK]	40.000	SOU 2013
BEV battery cost share	0.25	Nykvist, Nilsson, 2014
Small BEV battery cost [SEK/kWh]	3062	Nykvist, Nilsson, 2014
PHEV battery cost [SEK/kWh]	3832	Nykvist, Nilsson, 2014
Annual battery cost reduction	0.08	Nykvist, Nilsson, 2014
Gasoline price [SEK/liter]	14.50	SPBI, 2015
Diesel price [SEK/liter]	13.20	SPBI, 2015
Charging rate [kW]	3	Assumption
Electricity price [SEK]	1	Assumption
BEV manufactoring emissions [t CO_2-eq]	10.5	Wilson, 2013
PHEV manufactoring emissions [t CO_2-eq]	8	Wilson, 2013
Gasoline car manufactoring emissions [t CO_2-eq]	7	Wilson, 2013
Diesel car manufactoring emissions [t CO_2-eq]	7	Wilson, 2013
Electricity emissions [g CO_2-eq/kWh]	97.3	Brandsma, Friberg, 2013
Gasoline fuel emissions [g CO_2-eq/liter]	2770	Wilson, 2013
Diesel fuel emissions [g CO_2-eq/liter]	3240	Wilson, 2013
Minimum charging time [h]	4 or 10	Björnsson.,Karlsson, 2015

Depth of discharge displays how large amount of the electric battery that can be converted into mechanical energy. The number of years a car is kept before it is sold is uncertain and is therefore included in the sensitivity analysis. The electric car subsidy is currently 40.000 SEK but may increase in the future (SOU, 2013). The battery cost share for BEVs is the share of the total investment cost that consists of the battery as opposed to the chassi. To calculate how large the battery share is of the total investment cost for PHEVs, information that battery technology for PHEVs is 30-50% more expensive than for BEVs has been used (Nykvist, B., Nilsson, M., 2014). The total battery cost per kWh for BEVs were multiplied by a factor 1.4 (representing the higher cost for PHEV batteries), then multiplied by the size of the battery and finally divided by the investment price of the PHEV. The gasoline and diesel price is the price in 2013 and are assumed to increase proportionally with the oil price.

The emission related parameters are under the assumption that all cars are medium sized and that gasoline cars emit the same amount of CO_2-eq during production as diesel cars. Since the increase of electric vehicles happens gradually, the electricity production is assumed to use the electricity mix that is used in the Nordic energy market today as opposed to marginal electricity production which is used for sudden large increases of energy demand.

All results are presented in two cases: One case where electric cars are assumed to be charged at both the owner's home and work, meaning the car has to be parked for four hours before it can be assumed to be charged, and one case where the car will only be charged at home, which needs a ten hours parking time.

Table 2: Vehicle sized dependent parameters used in the model.

	Small	Medium	Large	
BEV battery capacity [kWh]	20	24	28	Gnann et al., 2014
PHEV battery capacity [kWh]	7	10	13	Gnann et al., 2014
BEV electricity consumption [kWh/km]	0.169	0.206	0.224	Gnann et al., 2014
PHEV electricity consumption [kWh/km]	0.159	0.196	0.213	Gnann et al., 2014
BEV investment cost [SEK]	245.000	387.000	794.000	Volkswagen, 2015
PHEV investment cost [SEK]	236.000	373.000	765.000	Volkswagen, 2015
Diesel investment cost [SEK]	146.000	231.000	474.000	Volkswagen, 2015
Gasoline investment cost [SEK]	128.000	202.000	414.000	Volkswagen, 2015
Diesel fuel consumption [liter/km]	0.042	0.051	0.083	Gnann et al., 2014
Gasoline fuel consumption [liter/km]	0.055	0.067	0.089	Gnann et al., 2014

Table 2 displays the data that are dependent on vehicle type. To make a fair comparison between vehicle investment costs, cost approximations have been found for several different Volkswagen cars, in the categories small and medium gasoline car (High Up and Golf), medium and large diesel car (Golf and Touareg), medium BEV (e-Golf) and medium PHEV (Golf GTE). These costs have then been used to estimate the costs of the remaining vehicle categories, with the assumption that the cost ratios between vehicle sizes are equal for all vehicle types. This was necessary because of a lack of comparable Volkswagen cars of all sizes and categories. The hybrid vehicles are assumed to run on electricity and gasoline and have the same gasoline consumption as the gasoline cars when driven on only gasoline.

2.4 Additional cases

In this part it will be explained how additional cases differs from Base case and what parameters have been changed or added in the model for these cases.

2.4.1 Increase of fuel tax

In 2014, the total tax on gasoline and diesel excluding sales tax was 40 % of the total price (SPBI, 2015). This may however increase in the future as a measure to lower the CO_2 emissions in Sweden. The effect of increasing the tax by 50, 100 and 150 % for both fuel types will be tested.

An increase of the fuel price will lead to higher running costs for conventional vehicles, but also hybrid vehicles will be affected to a lesser degree.

2.4.2 Subsidy for electric vehicles

Currently, the Swedish government offers a 40.000 SEK subsidy to everyone who buys an electric vehicle. The Swedish department of environment and energy is however suggesting a raise of the subsidy to 70.000 SEK to increase the purchase rate of electric vehicles (SOU, 2013).

In order to investigate how a higher electric car subsidy (which directly corresponds to a lower investment cost) would affect the diffusion of electric vehicles on the market, the subsidies have been varied between 40.000 and 80.000 SEK in steps of 10.000 SEK.

2.4.3 Increase in electricity price

The future price of electricity is uncertain. In Base case an electricity price of 1 SEK per kWh was used for the cost calculations and an assumption was made that the development of the electricity price would have low impact on the diffusion of electric vehicles on the market. This assumption is based on knowledge that the running cost of electric vehicles is significantly lower than conventional vehicles and it is primarily the large difference in investment cost that is the barrier for penetration of more electric vehicles on the market. To test that the assumption was correct the electricity price is increased by 50%, 100% and 150%..

2.4.4 Part of battery progress used to increase battery capacity

The electric vehicles have two major disadvantages: the cost associated with the battery and limited capacity of the battery. It is assumed in Base case that the cost of batteries is reduced by 8% each year while the capacity size remains unchanged (Nykvist, B., Nilsson, M. 2014). In this case, a portion of the price reductions is instead redirected to increase the capacity of the batteries. The share of the battery development that is invested into the capacity instead of the price has been varied between 0% (Base case), 25%, 50%, 75% and 100%. A share of 100% means the battery prices are constant while the capacities increases by 8% per year.

This implies that the amount of possible BEVs increase each year when further distances are possible to travel before charging the batteries.

2.4.5 Option to rent a vehicle

One of the more significant barriers for the diffusion of BEV on the market is the limited range of the vehicles. An option for the owners of BEV would be to rent a vehicle for the trips when the capacity of the electric battery is not sufficient to complete the trip. In this case this is modeled by checking the status of the battery. Every time the amount of power left in the battery becomes negative an initial cost of 60€ that corresponds to the leasing cost of a vehicle is added to the total cost (Jakobsson et al., 2014). Every trip that is made within the next coming 24 hours is assumed to be made with a rental vehicle and the price and emissions of the fuel is calculated as a gasoline car. After the 24 hours the battery in the BEV is fully charged.

2.4.6 Vehicle possession times

The vehicles possession time has an effect on what type of car that minimizes the total cost for an owner. The longer a car owner keeps the car before it is sold, the larger the running cost is compared to the investment cost. In Base case it is assumed that every car is being kept for 8 years. In order to investigate how large impact the vehicle possession time (and thus driving costs) have on the model a case has been made where the number of years varies from two to eleven years in increments of three. Depending on the possession time the resale value will vary with lower possession times leading to higher resale values. The share of the investment cost that is refunded when the car is sold after a certain number of years has been obtained by a used car evaluation site (AutoUncle, 2015), where data from the considered car models has been used to receive an average share of the investment cost. The parameters that concern other than eight years are shown in table 3.

Table 3: Refund share for different vehicle possession times.

Refund share 2 years	0.75
Refund share 5 years	0.50
Refund share 8 years	0.30
Refund share 11 years	0.25

2.5 Car movement data

In this study, a database with the characteristics of movement patterns of driven private cars in south-western Sweden (corresponding to roughly 1/6 of the total number of cars and inhabitants in Sweden) during 2010 to 2012 has been used (Karlsson, 2013). The database does not include commercial vehicles, vehicles with a weight over 3.5 tons or vehicles of a model year 2002 or earlier. A total of 12357 persons were asked to participate in the study, which was divided into nine campaigns, and 932 gave a positive answer. Out of these, 528 have had their movements logged for at least 30 days, and over 450 cars have been logged for over 50 days. In this study, only data from 429 cars have been used due to incomplete data logging and a minimum logging time of 30 days. Signals such as timestamp, position and velocity were recorded by GPS each time the car was started. A few resulting parameters can be seen in Table 4.

Table 4: Example of parameters from the database: The model year, car weight and fuel usage are taken from all cars that registered data (714 cars). The remaining values are taken from the 445 cars that did not include faulty data logging (Karlsson,, 2013).

Average model year	2006.37
Average curb weight	1456
Average fuel usage [liter/100km]	7.22
Average trip length [km]	10.4
Average number of trips per day	4.4

The 528 cars have been divided into three weight categories. This was necessary because of the difference in car properties depending on car size such as fuel consumption. In this study, the weight limit for small cars is below 1200 kg and for large cars above 1900 kg. The curb weights were found in the database via their license number. This resulted in 88 small cars, 330 medium-sized cars and 11 large cars.

To determine whenever each car have access to an electric charging station between driving trips, the pauses after each trip have been gathered from the database. The results from this study have been divided into two parts: One part where PHEVs and BEVs are assumed to be charged at home only (which is modeled as whenever a car is parked for more than ten hours), and one part where charging stations are located both at home and at work (which means the car only has to be parked for more than four hours in order to be assumed to be charged).

In the total cost analysis, the annual fuel costs depend on the total distance each car is driving each year. The logged driving distances are extrapolated to one year and are taken from the database. The same distances will be used for each year.

3. Results

3.1 Base case

3.1.1 Year 1

In Base case all four of the different scenarios will have the same result for year 1. This is purely a coincidence and would not necessary be true for a different database of car movements. For the scenario with the same charging time but different fuel price developments, the results will always be the same during year 1. The reason for this is that the development of the fuel price will not differ during the first year. However, for the scenarios with different charging time the results could differ. In Base case and all the other cases where the capacity of the battery is not increased, 69 users (16% of the total amount of users) would be able to complete all their trips with a BEV when the minimum stopping time for charging is four hours and 43 users (10%) are able to complete their trips with an electric vehicle when the minimum stopping time for charging is ten hours. The single user that minimize its cost with an electric vehicle in this case, can complete all trips with both four and ten hours stopping time for charging.

Table 5: Market share and CO_2-eq emissions for Base case for year 1.

Year 1	A	B	C	D
Gas [%]	33.1	33.1	33.1	33.1
Diesel [%]	66.6	66.6	66.6	66.6
PHEV [%]	0	0	0	0
BEV [%]	0.2	0.2	0.2	0.2
CO_2-eq [Mton]	1.13	1.13	1.13	1.13

In Base case the model shows that if the users would invest in a vehicle according to a cost minimization strategy the distribution of different vehicles types in year 1 will be 33.1% gasoline vehicles, 66.6% diesel vehicles, 0% PHEVs and 0.2% BEVs. This can be compared to data of sold private cars in the month of February 2014 that showed that 34.3 % of the sold private vehicles were gasoline vehicles, 60.1 % diesel vehicles, 0.6% PHEVs, 0.3 % BEVs and 4.7% miscellaneous cars (Statistiska centralbyrån, 2015). When only looking at the different vehicle types that is in the model, i.e. not including miscellaneous cars, the numbers would be 35.8% gasoline vehicles, 63.3 % diesel vehicles, 0.6% PHEVs and 0.3% BEVs. The Table 5 shows the market share for the four different vehicles types and scenarios. The table also shows the added emissions of CO_2-eq for the added car fleet for year 1.

The cost minimization calculations showed that the average driving distance for year 1 for users that would minimize their total cost by buying a gasoline vehicle was around 7500 km and for diesel vehicles the average distance was around 22.000 km. For the single user that would minimize its cost with a BEV the yearly travelled distance was almost 16.000 km. The average distance in the model is 17153 km/year. According to Statistics Sweden the average Swedish driver drove 14540 km in year 2009 (Statistiska centralbyrån, 2010). The reason for the higher average distance is that the database is based on relatively new cars that tend to drive more than older cars.

3.1.2 Year 12

In the results for year 12 the four different scenarios will have a more apparent effect on the results. A higher price for conventional fuel will reduce the amount of gasoline vehicles sold on the market. This is not necessarily true for diesel vehicles. A high oil price combined with high possibilities for charging will lead to a decrease of diesel vehicles when the amount of electric vehicles grows. However a high oil price combined with low possibilities for charging will lead to a growth of diesel vehicles sold on the market. This is due to the lower running costs of diesel vehicles compared to the gasoline vehicles. The market shares of each vehicle type each year is shown in Figure 3. In Table 6 a more detailed result for year 12 is presented.

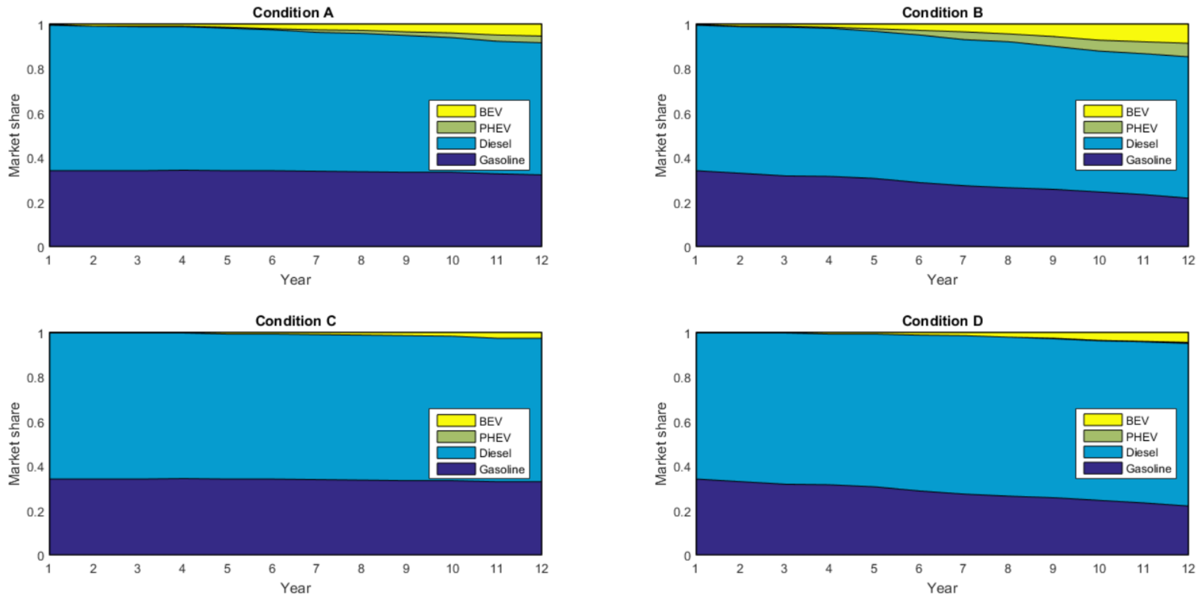

Figure 3: Graphs showing the market share for all vehicle types for each scenario from year 1 to year 12.

Table 6: Market share and CO_2-eq emissions for Base case for year 12.

Year 12	A	B	C	D
Gas [%]	32.40	21.68	32.40	21.68
Diesel [%]	61.31	65.27	65.27	73.89
PHEV [%]	1.63	4.90	0	0.23
BEV [%]	4.66	8.16	2.33	4.20
CO_2-eq [Mton]	1.09	1.04	1.12	1.11

As might be assumed, higher oil prices will also lead to a higher market diffusion of BEVs and PHEVs. It is important to remember that compared to year 1 the battery cost for the electric vehicles has also been reduced with 8% for each year. An interesting note is that the charging possibilities will have a much more significant effect for the PHEVs compared to

BEVs. The main reason for this is that when there is more possibilities to charge the vehicle the running cost will drop for PHEVs, because less conventional fuel has to be used, while the running cost for the BEVs will remain unchanged. Better possibilities for charging will however lead to more users that can drive with a BEV. From the calculations in this model the market potential for BEVs is higher in the future compare to PHEVs. The market potential for BEVs in year 12 is presented in Figure 4.

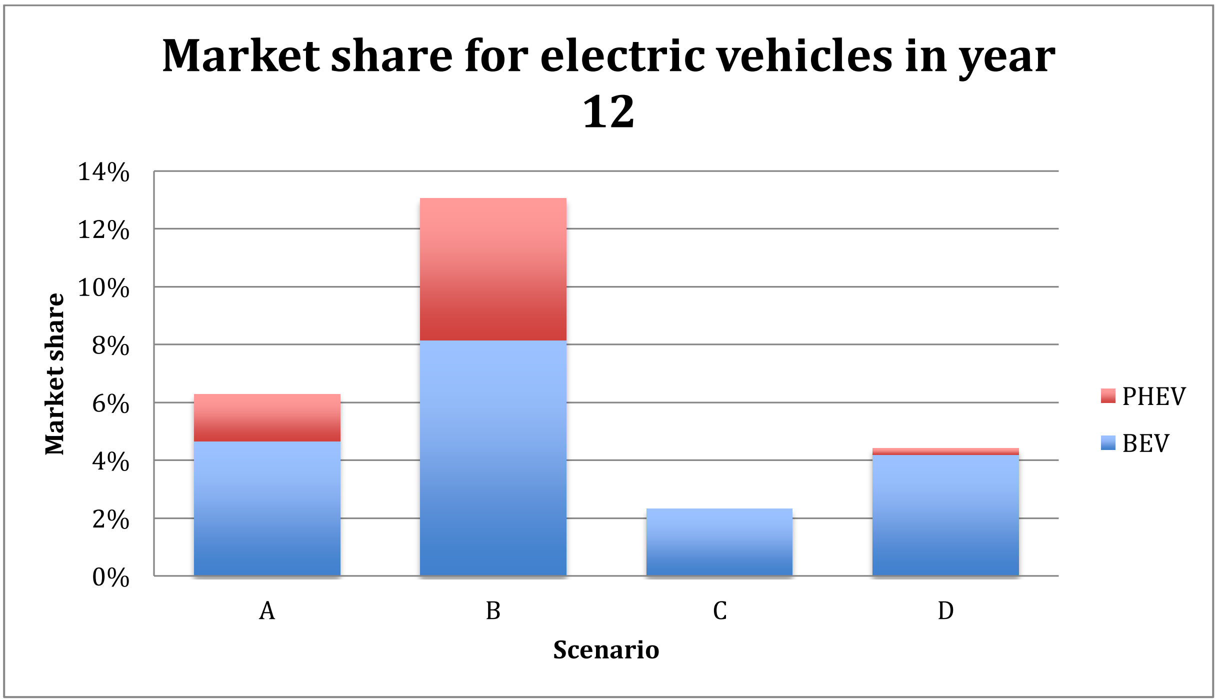

Figure 4: The market share for electric vehicles in year 12 for the four different scenarios.

The model shows that the total market share for electric vehicles will be 2.3-13.1% depending on scenario. The added emissions from the new car fleet will decrease by 0.5-7.4% compared to year 1 as can be seen in Figure 5. The blue staple represents the added total CO_2-eq emissions of the added car fleet for one year. The red staple is the reduction of total emissions from the added car fleet for one year compared to the added car fleet in year 1. When adding the blue and the red staple the sum will be equal to the emissions from the added car fleet during year 1. The results show that better possibilities to charge the vehicles will have a larger impact in reduction of emissions than increase of oil prices in the model. Better possibilities for charging will lead to a doubling of the amount of BEVs compared to lower possibilities for charging in year 12. The effects for hybrids are even larger.

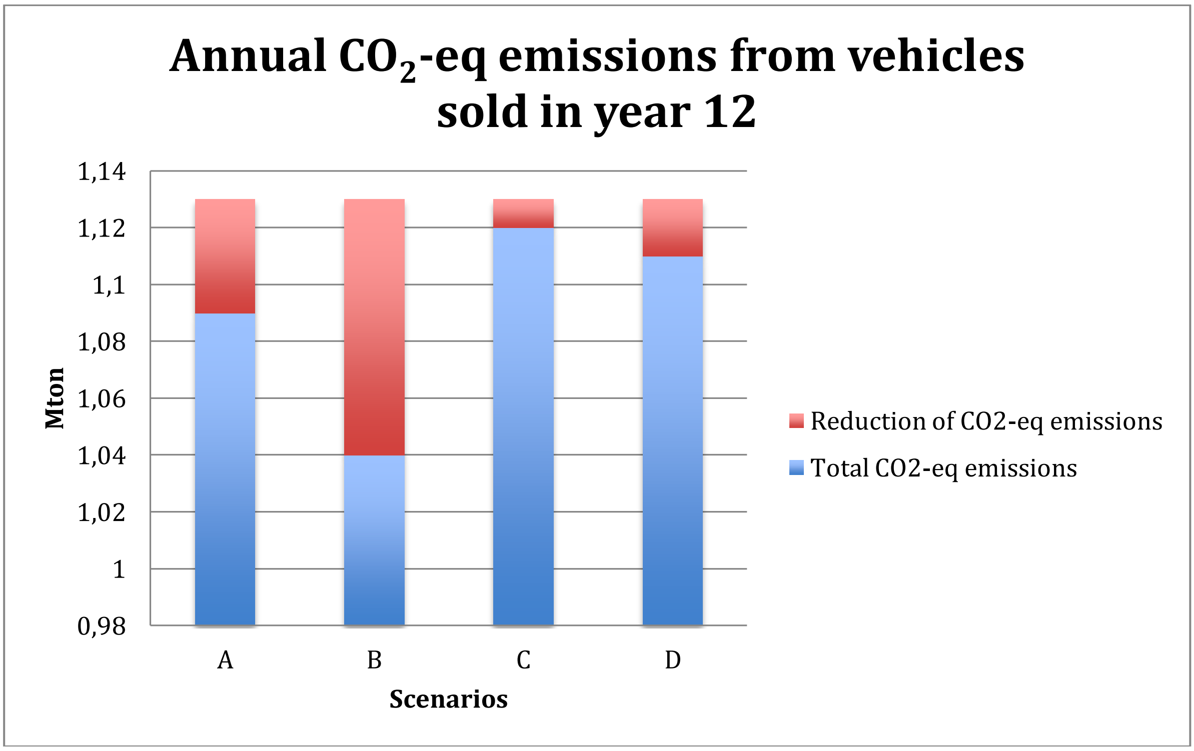

Figure 5: Total CO_2-eq emissions and the reduction of CO_2-eq for Base case.

Table 7: The average distance traveled during one year for the four vehicle types for all of the four different vehicle types in year 12.

average distance in year 12	A	B	C	D
Gas [km]	7608	6388	7608	6388
Diesel [km]	22433	21171	22150	20779
PHEV [km]	20104	20565	-	13037
BEV [km]	13029	11575	9931	9159

Table 7 shows the average distance car users drive in year 12 depending on vehicle type. In general, users that have the lowest yearly driving distances will minimize their total cost by investing in a gasoline vehicle. This is due to the lower investment cost, but gasoline vehicles are also associated with higher running cost. During the scenarios with higher oil price (B and D), the average distance is lower compared to scenarios with lower oil price (A and C). During scenario B and D the users that had the highest yearly travelled distance would lower their cost by investing in a vehicle with lower running cost.

Both diesel and PHEV users have very high average travelling distances compared to both gas and BEV users. This is explained by the high investment cost of the vehicles and the low running cost. The PHEV has a substantially higher investment cost than diesel vehicles, but also a lower running cost that is based on how large proportion of the distance that can be driven by the battery. The users that minimize their total cost with a PHEV have compared to diesel vehicle users more charging opportunities between trips and can travel more on battery, which reduces the running costs. For scenario D the average distance is very low compared to scenario A and C. That is due to only one user minimizes its total cost with a PHEV, making the average distance for PHEVs unreliable. From Table 8 it can also been seen that the amount of diesel vehicles is increasing for scenarios with high oil price. This is explained by the lower running cost of diesel vehicles compared to gasoline vehicles.

The average travelling distance of BEV is higher than gasoline vehicles and lower than PHEVs and diesel vehicles. For BEVs longer travelling distances are preferred due to the very low running cost. However, the limited capacity of the battery limits the distance travelled between charging stops. This can be seen by the higher average distances for the scenarios with shorter stops necessary for charging compared to the scenarios with longer stops necessary for charging. From the Table it can also be seen that higher oil prices will increase the amount of BEVs with shorter annual travelling distances.

Due to the fact that electric vehicles emit more CO_2-eq during production compared to conventional vehicles, there is a minimum total distance the vehicle has to drive before there is a reduction of emissions, see Figure 6. The total distance a BEV has to drive before it emits less than a gasoline vehicle has been calculated to be 21100 km. The corresponding value to a diesel vehicle is 24100 km. When assuming an eight year car-possession time, the annual distances are 2640 and 3010 km, respectively. These are significantly lower than the average travelling distances for the BEV users in Table 7.

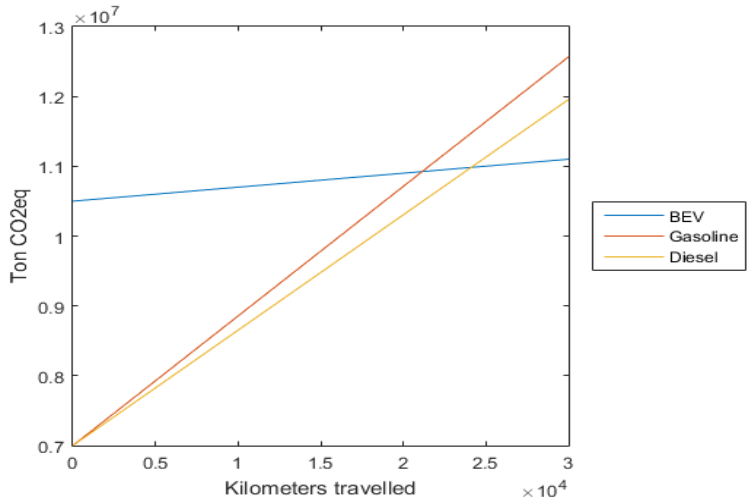

Figure 6: The total CO_2-eq emissions from production of the vehicle and from the driving.

3.2 Increased fuel tax

One possible way to increase the number of BEVs and PHEVs is to increase the tax of gasoline and diesel. Around 40% of the fuel prices today come from taxes, excluding sales tax, so a 50% tax increase leads to a 20% increase in fuel prices. These prices changes yearly by the oil price in the same way as in Base case. A total of three different tax levels were examined: a 50%, a 100% and a 150% increase.

For this case only the results from year 12 will be presented with the exception of a 50% increase of fuel tax. The reason for this is that it is not reasonable to increase the fuel tax by 100% or more in just one year. Even an increase of 50% is an extreme increase but is presented to show how higher oil prices affect the market share for electric vehicles today.

3.2.1 50% increased fuel tax

The results are shown in Table 8 and 9. The higher fuel prices compared to Base case are generally reducing the number of gasoline vehicles more than diesel vehicles due to their higher running costs. The total market share for electric vehicles in year 12 will be 4.0-20.3%. The savings of CO_2 emissions in year 12 compared to year 1 in Base case are 1.4% to 12.6%.

Table 8: Market share and CO_2-eq emissions for 50% increased fuel tax-case for year 1.

Year 1	A	B	C	D
Gas [%]	24.71	24.71	24.71	24.71
Diesel [%]	73.89	73.89	75.06	75.06
PHEV [%]	0.47	0.47	0.00	0.00
BEV [%]	0.93	0.93	0.23	0.23
CO_2-eq [Mton]	1.12	1.12	1.12	1.12

Table 9: Market share and CO_2-eq emissions for 50% increased fuel tax-case for year 12.

Year 12	A	B	C	D
Gas [%]	23.54	14.92	23.78	14.92
Diesel [%]	63.87	64.80	72.26	79.49
PHEV [%]	4.90	10.26	0.23	0.47
BEV [%]	7.69	10.02	3.73	5.13
CO_2-eq [Mton]	1.05	0.99	1.11	1.10

3.2.2 100% increased fuel tax

When the fuel taxes are doubled, there is a larger increase in purely electrical vehicles compared to hybrids when the charging opportunities are great (scenario C and D), see Table 10. This can be explained by the fact that BEVs do not use gasoline or diesel and thus are unaffected by the tax, and the number of BEVs are still small enough to have expansion potential, even when considering their limited battery sizes. The total market share for electric vehicles will be 5.6-28.0%. The CO_2 reduction is between 2.1% and 18.3%.

Table 10: Market share and CO_2-eq emissions for 100% increased fuel tax-case for year 12.

Year 12	A	B	C	D
Gas [%]	16.55	11.19	16.55	11.19
Diesel [%]	65.03	60.84	77.86	80.89
PHEV [%]	8.39	16.78	0.47	2.10
BEV [%]	10.02	11.19	5.13	5.83
CO_2-eq [Mton]	1.00	0.92	1.10	1.09

3.2.3 150% increased fuel tax

The highest fuel tax that is considered in this study is an increase by 150%. The results can be seen in Table 11. Comparing this with an increase of 100%, there is a larger increase in PHEVs than BEVs, which is because most of the drivers that are able to drive a BEV are already doing so, which saturates the market for BEVs. The total market share for electric vehicles is calculated to be 6.5-37.3%. The smallest savings of carbon dioxide is 2.8% and the largest is 24.1%.

Table 11:Market share and CO_2-eq emissions for 150% increased fuel tax-case for year 12.

Year 12	A	B	C	D
Gas [%]	13.52	7.69	13.75	7.93
Diesel [%]	63.64	55.01	79.72	79.49
PHEV [%]	12.59	24.48	1.40	5.59
BEV [%]	10.26	12.82	5.13	6.99
CO_2-eq [Mton]	0.96	0.86	1.10	1.06

The EV market share and emissions for different fuel taxes are shown in Figure 7 and 8. It can be seen that the number of EVs increase roughly linearly with the tax increase, and the PHEVs gain market shares faster than BEVs at increased taxes. This can be explained by that even due to the fact that PHEVs are negatively affected by the increased taxes while the BEVs are not, the limited number of people who are able to drive a BEV with their current driving pattern creates a limit for the BEV market share growth. When this limit is approached, more people are forced to buy a PHEV compared to a BEV. The emissions are reduced roughly at the same rate as the number of EVs increases.

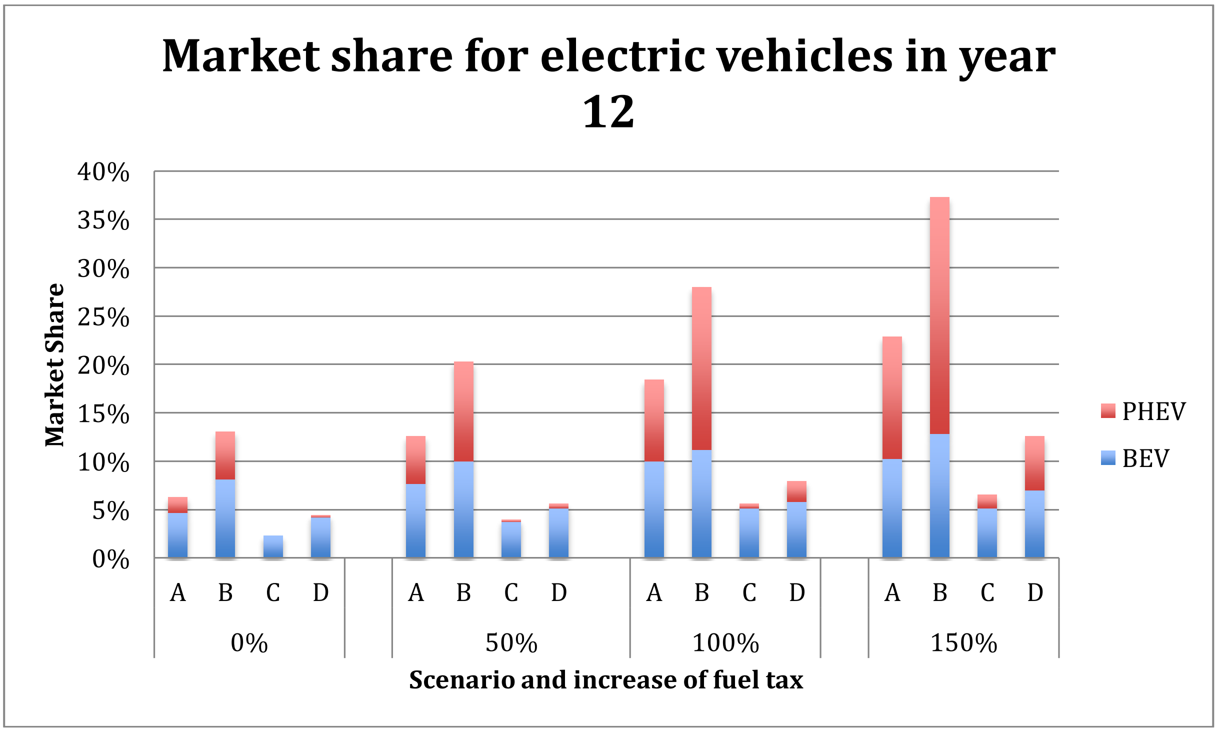

Figure 7: The market share for electric vehicles in year 12 for the four different scenarios and different tax increases.

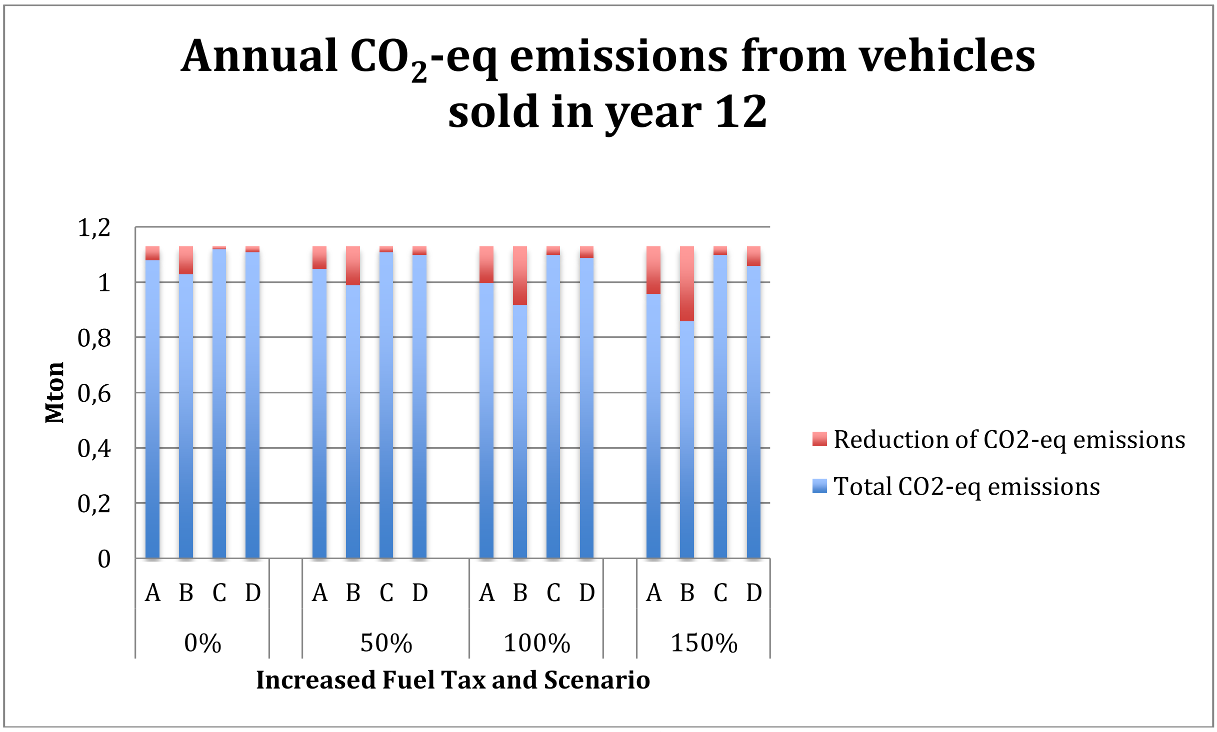

Figure 8: Total CO_2-eq emissions and the reduction of CO_2-eq for the increased fuel tax cases.

3.3 Increased subsidies for electric vehicles

In this case, the electric car subsidies has been increased from 40.000 SEK (current value) to up to 80.000 SEK.

3.3.1 50.000 SEK subsidy

An increment of the subsidy by 10.000 SEK effectively reduces the investment cost of BEVs and PHEVs by 10.000 SEK. For comparison, the prices to buy a medium sized BEV and PHEV are 387.000 SEK and 373.000 SEK, respectively. The market share of cars of each type in year 1 and year 12 along with emissions can be seen in Table 12 and 13. Subsidies seem to favor both hybrids and purely electric vehicles roughly equally. The total market share for electric vehicles will be 5.4-21.9%. The biggest emission reduction compared to year 1 in Base case is 13.0% and the smallest reduction is 1.5%.

Table 12: Market share and CO_2-eq emissions for 50.000 SEK subsidy-case for year 1.

Year 1	A	B	C	D
Gas [%]	33.10	33.10	33.10	33.10
Diesel [%]	65.27	65.27	66.67	66.67
PHEV [%]	0.93	0.93	0.00	0.00
BEV [%]	0.70	0.70	0.23	0.23
CO_2-eq [Mton]	1.12	1.12	1.13	1.13

Table 13 Market share and CO_2-eq emissions for 50.000 SEK subsidy-case for year 12.

Year 12	A	B	C	D
Gas [%]	28.67	19.11	30.77	20.75
Diesel [%]	57.11	58.97	63.87	71.79
PHEV [%]	6.29	11.89	1.17	2.33
BEV [%]	7.93	10.02	4.20	5.13
CO_2-eq [Mton]	1.04	0.98	1.11	1.10

3.3.2 60.000 SEK subsidy

In this case, a minimum charging time of four hours (scenarios A and B) leads to larger percentage change increase of BEVs compared to PHEVs, whereas the opposite is true for ten hours minimum charging time. This could be explained by the unequal number of PHEVs in the first year in these two cases, but mostly because of the higher minimum charging time is forcing more drivers to buy hybrid vehicles if they want to take advantage of the subsidy due to the battery limits of BEVs. The total market share for electric vehicles will be 14.0-34.5%. The emission reductions are now 5.2% to 20.8%. The market share of cars of each type in year 1 and year 12 along with emissions can be seen in Table 14 and 15.

Table 14: Market share and CO_2-eq emissions for 60.000 SEK subsidy-case for year 1.

Year 1	A	B	C	D
Gas [%]	32.40	32.40	32.63	32.63
Diesel [%]	61.54	61.54	65.73	65.73
PHEV [%]	5.13	5.13	0.70	0.70
BEV [%]	0.93	0.93	0.93	0.93
CO_2-eq [Mton]	1.08	1.08	1.12	1.12

Table 15: Market share and CO_2-eq emissions for 60.000 SEK subsidy-case for year 12.

Year 12	A	B	C	D
Gas [%]	24.48	16.32	27.27	17.72
Diesel [%]	49.88	49.18	58.74	64.80
PHEV [%]	14.69	22.38	7.93	10.72
BEV [%]	10.96	12.12	6.06	6.76
CO_2-eq [Mton]	0.97	0.89	1.07	1.04

3.3.3 70.000 SEK subsidy

This is the subsidy level that is recommended according to (SOU, 2013). Assuming an annual car sale rate of 300 000 (Statistiska centralbyrån, 2015), the subsidy increase would cost the Swedish government between 1.34 and 3.38 billion SEK in year 12 alone. Compared to the 60.000 SEK subsidy, more drivers are switching to PHEVs than BEVs. This happens since all drivers are not able to drive all their trips on a BEV battery, no matter the price. The total market share for electric vehicles will be 22.4-52.5%. The emission reductions lie between 10.1% and 32.6%. The market share of cars of each type in year 1 and year 12 along with emissions can be seen in Table 16 and 17.

Table 16: Market share and CO_2-eq emissions for 70.000 SEK subsidy-case for year 1.

Year 1	A	B	C	D
Gas [%]	29.60	29.60	30.07	30.07
Diesel [%]	55.48	55.48	62.47	62.47
PHEV [%]	13.99	13.99	6.53	6.53
BEV [%]	0.93	0.93	0.93	0.93
CO_2-eq [Mton]	1.02	1.02	1.09	1.09

Table 17: Market share and CO_2-eq emissions for 70.000 SEK subsidy-case for year 12.

Year 12	A	B	C	D
Gas [%]	21.21	12.82	24.24	14.92
Diesel [%]	40.56	34.73	53.38	54.78
PHEV [%]	25.87	38.00	15.38	21.68
BEV [%]	12.35	14.45	6.99	8.62
CO_2-eq [Mton]	0.87	0.76	1.01	0.96

3.3.4 80.000 SEK subsidy

The highest electric car subsidy that is considered in this study is 80.000 SEK. The number of BEVs is over time increasing at a higher rate than PHEVs, and the shares of possible BEV drivers that are minimizing the total cost by driving a BEV in year 12 are between 88.4% and 94.2%. The total market share for electric vehicles will be 36.9-67.1%. The CO_2 reductions are 19.0% to 42.4%. The market share of cars of each type in year 1 and year 12 along with emissions can be seen in Table 18 and 19.

Table 18: Market share and CO_2-eq emissions for 80.000 SEK subsidy-case for year 1.

Year 1	A	B	C	D
Gas [%]	26.34	26.34	26.34	26.34
Diesel [%]	47.79	47.79	56.41	56.41
PHEV [%]	24.94	24.94	16.08	16.08
BEV [%]	0.93	0.93	1.17	1.17
CO_2-eq [Mton]	0.95	0.95	1.04	1.04

Table 19: Market share and CO_2-eq emissions for 80.000 SEK subsidy-case for year 12.

Year 12	A	B	C	D
Gas [%]	17.02	10.02	20.51	12.35
Diesel [%]	27.97	22.84	42.66	40.09
PHEV [%]	40.33	51.98	27.97	38.46
BEV [%]	14.69	15.15	8.86	9.09
CO_2-eq [Mton]	0.74	0.65	0.91	0.84

The market share of electric cars in year 12 can be seen in Figure 9 and the emissions are shown in Figure 10. An increased subsidy favors hybrids more than battery electric cars due to the fact that everyone can buy a PHEV if they want to take advantage of the increased subsidy, while only a limited number of buyers are able to drive a BEV without changing its driving pattern, increasing the odds of PHEV market share growth.

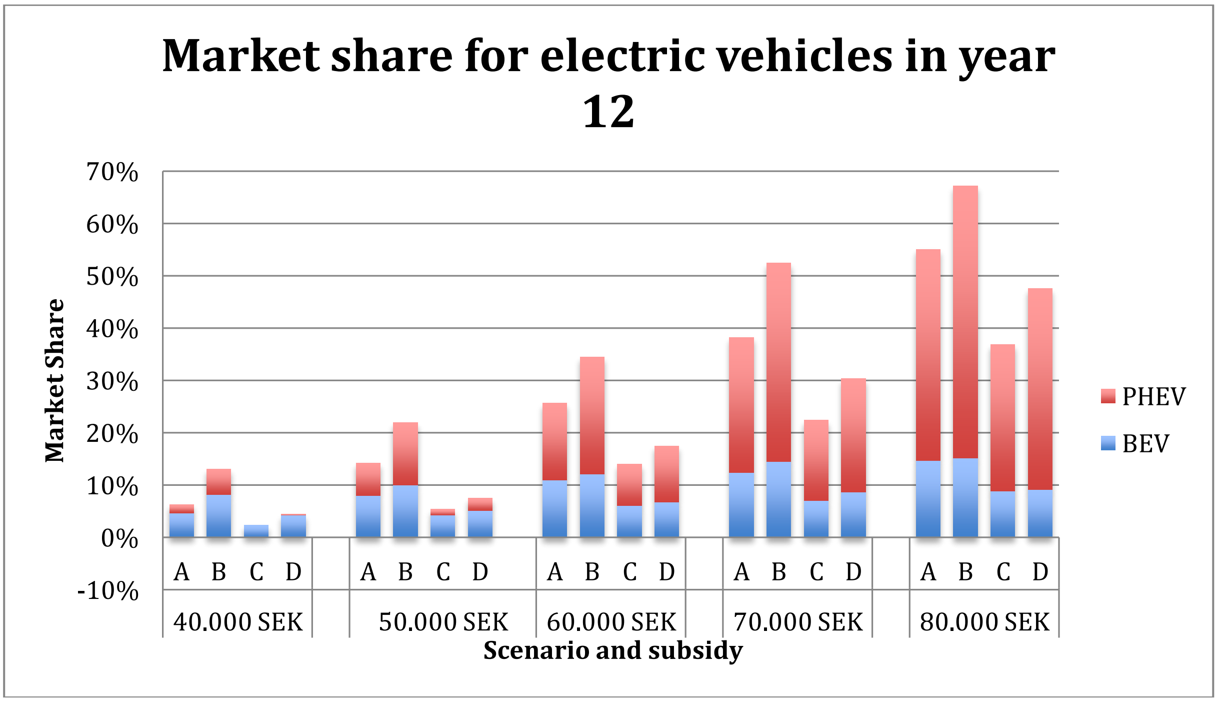

Figure 9: The market share for electric vehicles in year 12 for the four different scenarios and different subsidies.

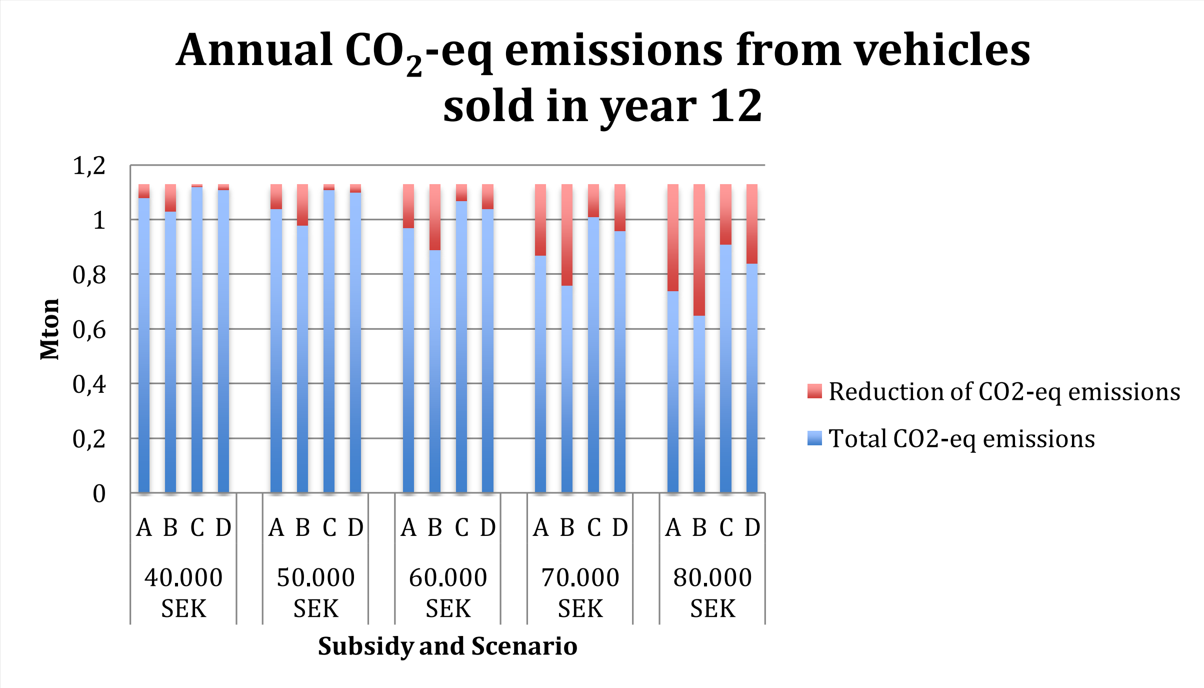

Figure 10: Total CO_2-eq emissions and the reduction of CO_2-eq for the increased subsidy cases.

3.4 Increase of the electricity price

This case investigates the car fleet development if the electricity price increases. This change would put BEVs and PHEVs at a disadvantage compared to diesel and gasoline cars.

For this case only the results from year 12 will be presented. The reason for this is that even in the case where the electricity price is increased with 50% the effect will be that all the electric vehicles are removed from the market in year 1.

3.4.1 50% increase of the electricity price

As expected, the amount of BEVs and PHEVs decrease with increased price on electricity. The BEVs and PHEVs are completely eliminated from the market in year 1. A minor note is that a few drivers switch from diesel cars to gasoline cars in scenario A. This is because in scenario A, the oil price is decreasing over time rather than increasing. The total market share for electric vehicles will be 1.4-9.8%, see Table 20. The emission reduction compared to Base case lies between 0.24% and 5.3%.

Table 20: Market share and CO_2-eq emissions for 50% increase of the electricity-case for year 12.

Year 12	A	B	C	D
Gas [%]	32.87	21.91	32.87	21.91
Diesel [%]	63.87	68.30	65.73	74.83
PHEV [%]	0.23	3.26	0.00	0.00
BEV [%]	3.03	6.53	1.40	3.26
CO_2-eq [Mton]	1.11	1.07	1.12	1.11

3.4.2 100% increase of the electricity price

When the electricity price is doubled compared to Base case (from 1 SEK to 2 SEK), the total amount of BEVs and PHEVs in year 12 is reduced by 50% compared to a 50% increase in price, suggesting a nonlinear relation between electricity price and electric vehicle competiveness. The reason behind this is might be the low number of BEVs and PHEVs, which may inflate the results. For many users, there is a small difference in total cost of ownership between vehicle types, which may tip the cost in favor of diesel and gasoline cars even in small increments of electricity prices. As can be seen in Table 21 the total market share for electric vehicles will be 0.9-4.2%. The CO_2 reductions are 0.2% to 2.0%.

Table 21: Market share and CO_2-eq emissions for 100% increase of the electricity-case for year 12.

Year 12	A	B	C	D
Gas [%]	33.33	22.61	33.33	22.61
Diesel [%]	65.03	73.19	65.73	75.52
PHEV [%]	0.00	0.23	0.00	0.00
BEV [%]	1.63	3.96	0.93	1.86
CO_2-eq [Mton]	1.12	1.10	1.13	1.12

3.4.3 150% increase of the electricity price

The same trend holds for a 150% price increase, to the point of nearly removing electric cars from the market completely. The total market share for electric vehicles will be 0.2-2.6%, as can be seen in Table 22. The smallest emission saving is very close to 0 and the highest is 1.4%. The close to zero emission reduction compared to Base case means the increase in electricity price negates the battery price decrease and the resulting market shares will be almost the same as in year 1 for Base case.

Table 22: Market share and CO_2-eq emissions for 150% increase of the electricity-case for year 12.

Year 12	A	B	C	D
Gas [%]	33.57	23.08	33.57	23.08
Diesel [%]	65.50	74.36	66.20	75.52
PHEV [%]	0.00	0.00	0.00	0.00
BEV [%]	0.93	2.56	0.23	1.40
CO_2-eq [Mton]	1.12	1.11	1.13	1.12

The market share of EVs and the total emissions in year 12 can be seen in Figure 11 and 12. Since the running costs of BEVs are directly connected with the price of electricity while PHEVs depend on both electricity and gasoline, a natural assumption is that the price increase would have a larger negative effect for BEVs compared to PHEVs. However, the PHEVs are in fact reduced at a faster rate than BEVs. One explanation could be due to the fact that the BEVs are increasing their market share a few years before the PHEVs. This means that the cost of PHEVs are closer to other types of cars compared to BEVs, which leads to bigger drops of market penetration when the price of electricity increases.

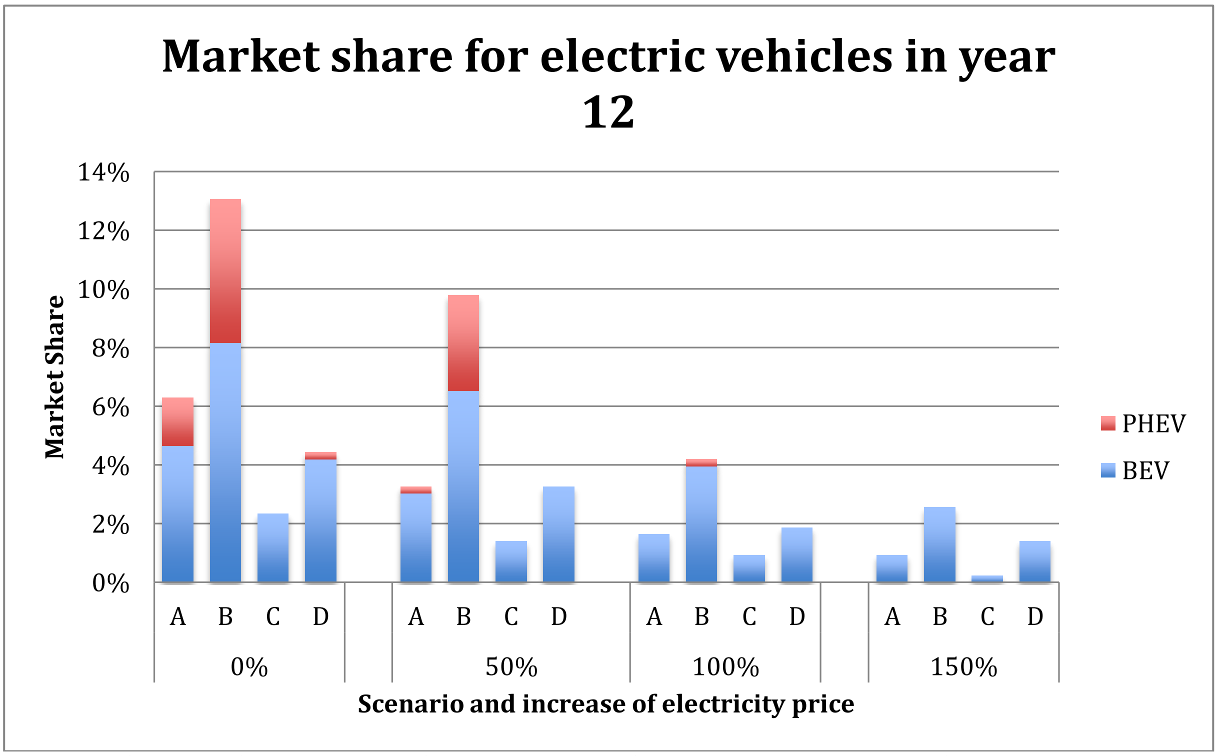

Figure 11: The market share for electric vehicles in year 12 for the four different scenarios and the different increases of the electricity price.

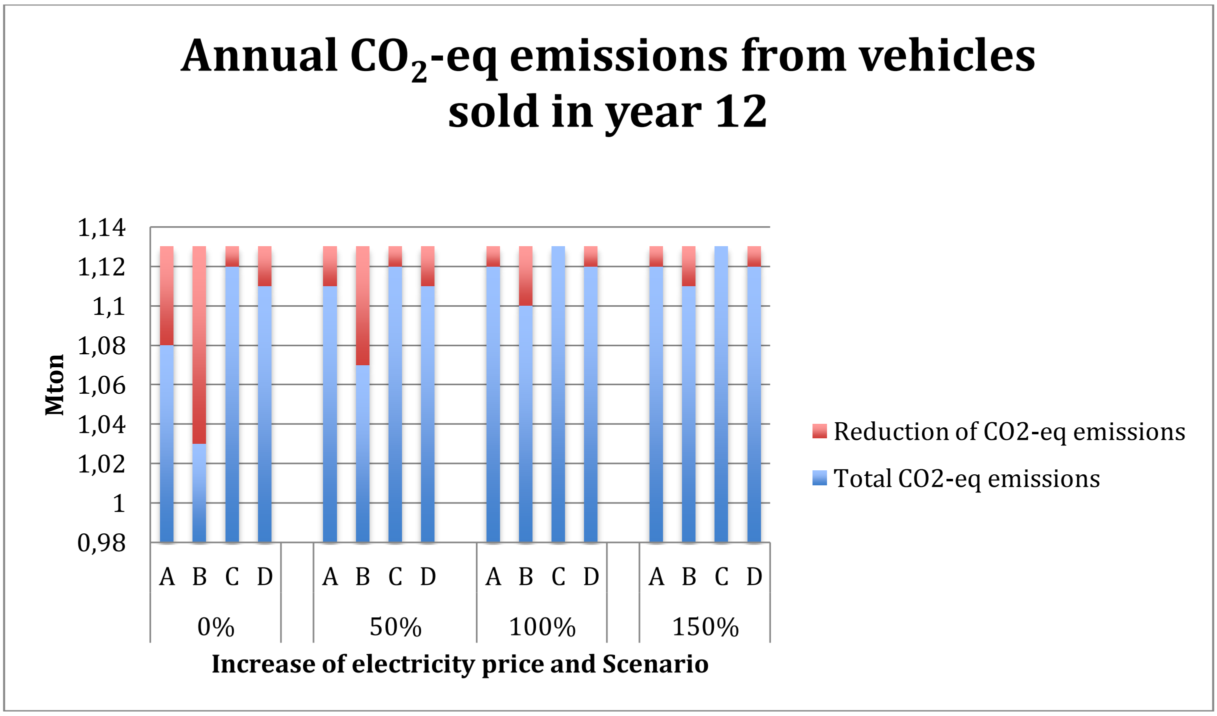

Figure 12: Total CO_2-eq emissions and the reduction of CO_2-eq for the increased electricity price cases.

3.5 Part of battery progress used to increase battery capacity

This case only presents the results for year 12. The reason for this is that for year 1 the development of the battery prices, and battery capacity will not have started yet and will be the same as for Base case.

3.5.1 25% of the battery progress to battery capacity (C25/P75)

Table 23: Market share and CO_2-eq emissions for C25/P75-case for year 12.

Year 12	A	B	C	D
Gas [%]	32.63	22.14	32.63	22.14
Diesel [%]	59.21	62.00	65.03	72.96
PHEV [%]	3.03	6.76	0.00	0.47
BEV [%]	5.13	9.09	2.33	4.43
CO_2-eq [Mton]	1.09	1.04	1.12	1.11

When using 75% of the progress of the battery development to reduce the price and 25% to increase the capacity of the battery, it will overall be positive for the market diffusion of electric vehicles, see Table 23. The amount of BEVs and PHEVs will increase compared to Base case for scenario A, B and D and will remain the same for scenario C. Another interesting side of the results is that the gasoline vehicles are growing in numbers while the diesel vehicles are declining in numbers when 25% of the development is used to increase the capacity. The reason for this is that gasoline vehicles' major economic advantage is that they have a comparatively low investment cost. The running cost however is high for gasoline vehicles. This means that gasoline car drivers have quite low average driving distances. The best way for electric vehicles to compete against gasoline vehicles is therefore to reduce the prices of the batteries in favor of increasing the capacity. For diesel vehicles however the investment cost is higher while the running cost is lower. This means that the average driving distance is quite high for diesel vehicles. The limited capacity of the battery will therefore lead to a proportion of the diesel car drivers being unable to use a BEV for their driving pattern. When the capacity of the battery is raised more diesel car drivers will be able change to a BEV.

Even if both BEVs and PHEVs gain from using 75% of the battery progress to price reduction and 25% to capacity increase, the percentile growth is larger for PHEVs even if the increase in absolute amount of cars is increased for BEVs. The total market share for electric vehicles will be 2.3-15.9%, see Table 23.

For all scenarios there will be a decrease in emissions in C25/P75 compared to Base case. The decrease of CO_2-eq emissions lies between 0.7 and 10.7%. One of the reasons for the reduction is that the number of electric vehicles is increasing. Another important note is that the number of diesel vehicles is decreasing in favor for gasoline vehicles and electric vehicles, since diesel vehicles emit less than gasoline vehicles.

3.5.2 50% of the battery progress to battery capacity (C50/P50)

Table 24: Market share and CO_2-eq emissions for C50/P50-case for year 12.

Year 12	A	B	C	D
Gas [%]	33.57	22.61	33.57	22.61
Diesel [%]	58.51	59.44	64.10	71.33
PHEV [%]	2.33	7.93	0.00	0.93
BEV [%]	5.59	10.02	2.33	5.13
CO_2-eq [Mton]	1.06	0.97	1.12	1.09

For C50/P50, the number of BEVs is increasing compared to Base case in all the scenarios except for C where the oil price is low and opportunities for charging is low, see Table 24. For C50/P50 the number of BEVs is the same as in Base case. However, the numbers of gasoline vehicles is slightly increasing and the same number of diesel cars is decreasing. As an effect of the price increase some of the BEV users has instead become gasoline vehicle users. However, the same number of diesel vehicle users has become BEV users as an effect of the increased capacity. Compared to Base case the number of hybrid vehicles will increase for all scenarios. See Table 24 for the market share of the different vehicle types in year 12.

Compared with C25/P75, the number of BEVs increase in all scenarios except scenario C. We will see the same effect as when comparing to Base case where old users of BEVs change to a gasoline car and the same number of diesel users change to a BEV. The number of hybrids for C50/P50 is only increasing compared to C25/P75 for scenario B and D and is decreasing for scenario A. The total market share for electric vehicles will be 2.3-18.0%.

Compared to Base case and C25/P75 the emissions will be decreasing for all scenarios. The CO_2-eq emissions are decreasing with 1.0-14.3% compared to Base case. The reason the environmental impact is decreasing for scenario C compared to C25/P75, even though the number of electric vehicles is the same is that the number of diesel vehicles is decreasing in favor of gasoline vehicles. This happens because drivers are able to transition from diesel to BEVs when the battery capacity increases, while others switch to gasoline from BEVs because of their higher investment cost compared to C25/P75.

3.5.3 75% of the battery progress to battery capacity (C75/P25)

Table 25: Market share and CO_2-eq emissions for C75/P25-case for year 12.

Year 12	A	B	C	D
Gas [%]	33.57	23.08	33.57	23.08
Diesel [%]	59.67	57.81	64.10	69.00
PHEV [%]	2.80	9.56	0.00	2.10
BEV [%]	3.96	9.56	2.33	5.83
CO_2-eq [Mton]	1.07	0.94	1.11	1.07

Compared to Base case C75/P25 will increase the number of BEVs for scenario B and D and decrease the number of BEVs for scenario A, Table 25. However, the number of hybrids is increasing for all scenarios except C where there are no hybrids for neither Base case nor C75/P25.

Compared with C50/P50 the number of BEVs is only slightly increasing for scenario D. The number of BEVs is however decreasing for A and B. The hybrids are compared to C50/P50 increasing for all scenarios except C where the number of PHEVs remains zero. The total market share for electric vehicles will be 2.3-19.1%, and the CO_2-eq emissions are 1.2 to 17.0%. See Table 25 for the market share of the different vehicle types and CO_2-eq emissions in year 12.

The emissions from the new cars during year 12 will decrease compared to Base case for all scenarios and compared to C50/P50 the environmental impact will decrease for scenario B, C and D. An interesting note is that the emissions are reducing for scenario C even though the market share of the different vehicles types are the same. The reason for this is that the battery capacity for the hybrids are larger in C25/P75 compared to C50/P50. As an effect less conventional fuel has to be used for the same trips.

3.5.4 100% of the battery progress to battery capacity (C100/P0)

Table 26: Market share and CO_2-eq emissions for C100/0-case for year 12.

Year 12	A	B	C	D
Gas [%]	33.57	23.08	33.57	23.08
Diesel [%]	59.44	58.51	64.80	67.83
PHEV [%]	5.36	12.35	0.93	4.66
BEV [%]	1.63	6.06	0.70	4.43
CO_2-eq [Mton]	1.05	0.92	1.12	1.04

Compared to C75/P25 the amount of BEVs will be lower for all scenarios but the amount of PHEVs will be higher. See Table 26 for the market share of the different vehicle types in year 12.

Compared to Base case the emissions will decrease for all scenarios. Compared to C75/P25 the emissions will decrease for all scenarios except for C. The main reason why the environmental impact is the lowest for C100/P0 is that the large battery capacity makes the PHEVs drive more than 90 % on electricity. The emissions during production of PHEVs are also substantially lower compared to BEVs. When a large share of the BEV-users changes to a PHEV the emissions from the production are reduced substantially and the large battery capacity reduces the difference of CO_2-emissions when driving. The CO_2-eq emissions compared to Base case lie between 1.1 and 18.2%.

Compared to Base case there is a reduction of market potential for BEVs for all scenarios except for scenario D. However, PHEVs are increasing its market potential for all scenarios compared to Base case. That gives a hint that increasing of the battery capacity is more important for the market diffusion of hybrid vehicles than reduction of the price of the battery. When increasing the capacity for the battery the effect will be a lower running cost when less conventional fuel has to be used. The total savings from lowering the running cost seems to have a larger effect for hybrids than the lower investment price when reducing the cost of the batteries. The total market share for electric vehicles will be 1.6-18.4%. The market share of EVs and the total emissions in year 12 can be seen in Figure 13 and 14.

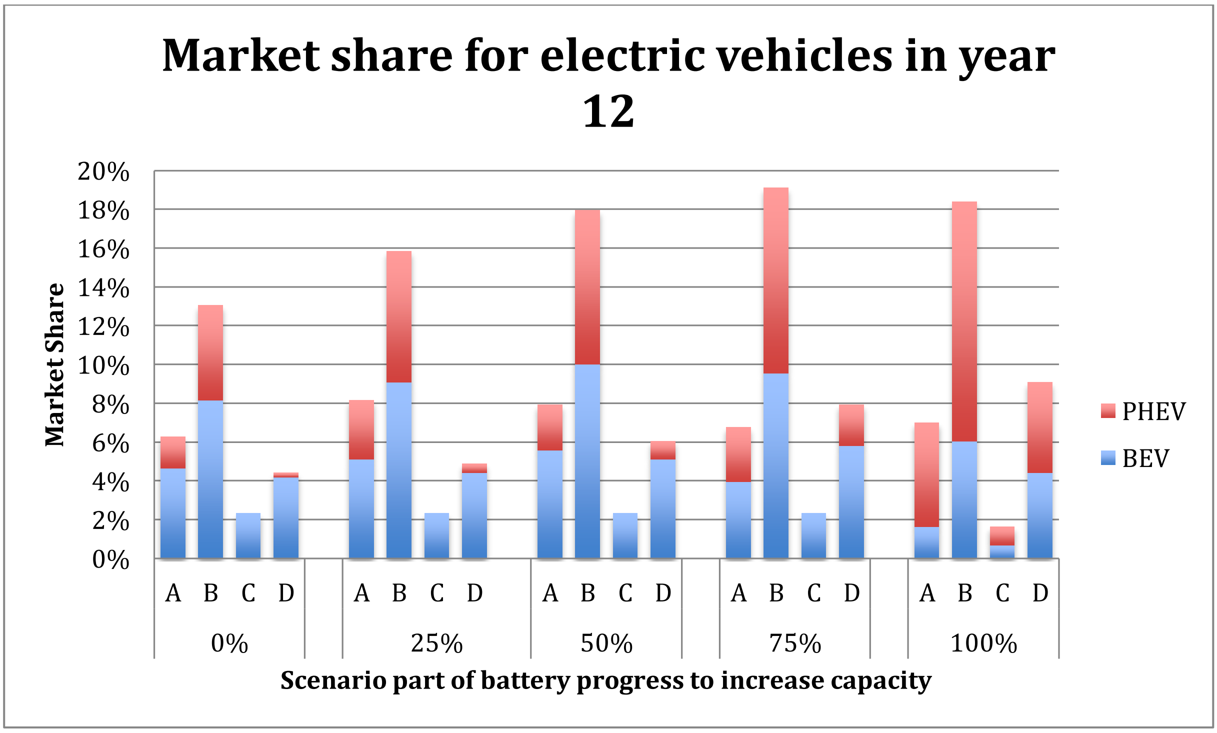

Figure 13: The market share for electric vehicles in year 12 for the four different scenarios and the different cases for part of progression of battery that goes to increasing the capacity.

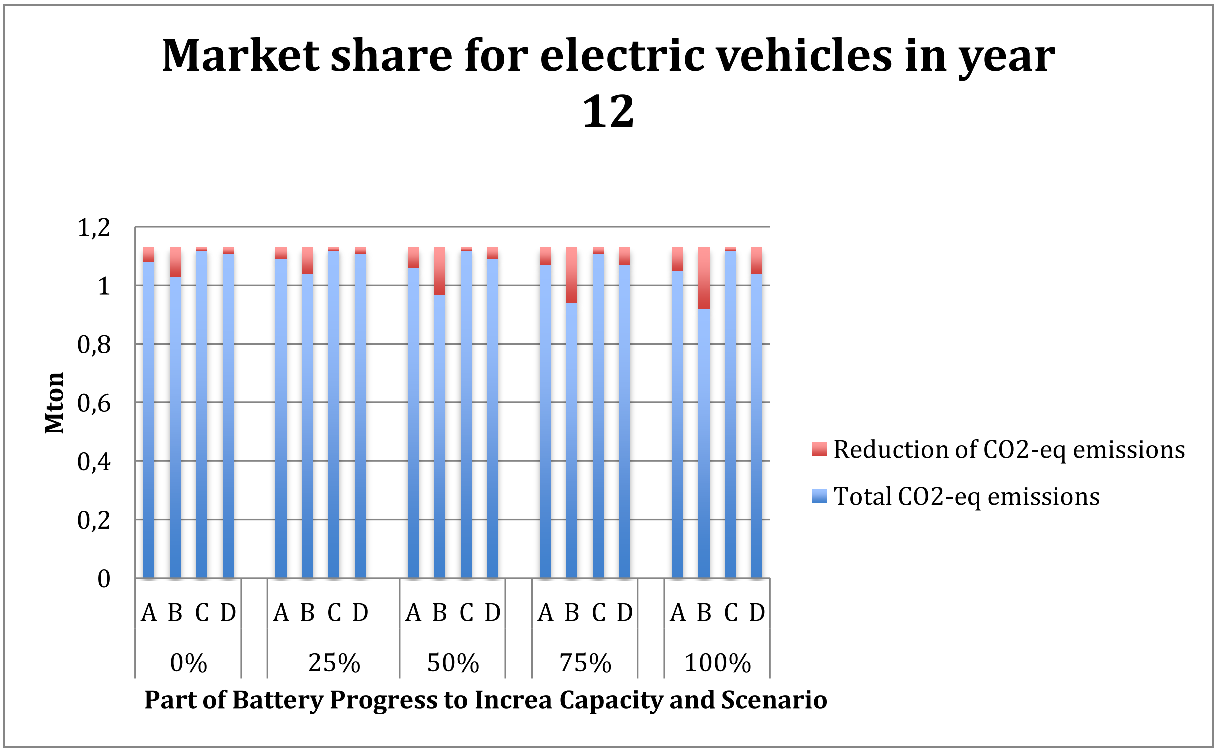

Figure 14: Total CO_2-eq emissions and the reduction of CO_2-eq for part of progression of battery that goes to increasing the capacity.

3.6 Option to rent a vehicle

In this case it is examined how an option to rent a vehicle when the battery capacity is not sufficient will affect the market share for electric vehicles. For year 1 the results for this case happens to be exactly the same as for Base case and will therefore not be further explained.

Table 27: Market share and CO_2-eq emissions for option to rent a vehicle-case for year 12.

Year 12	A	B	C	D
Gas [%]	32.40	21.68	32.40	21.68
Diesel [%]	60.37	64.80	65.27	73.43
PHEV [%]	0.93	2.33	0.00	0.23
BEV [%]	6.29	11.19	2.33	4.66
CO_2-eq [Mton]	1.09	1.05	1.12	1.11

For year 12 when there is a possibility for users of BEVs to rent a vehicle the amount of gasoline vehicles will be the same as for Base case, see Table 27. The reason behind this is that users that minimize their cost by buying a gasoline vehicle in general drives less than users that minimize their total cost by buying a diesel vehicle or a PHEV. Most of the gasoline vehicle drivers could already in Base case finish their trips with a BEV but it would increase their total cost.

For diesel vehicles there will be a small transition to BEVs for all scenarios except C. The most substantial effect in this case is that there is relative large transition from PHEVs to

BEVs for scenario A and B. The total market share for electric vehicles will be 2.3-13.5%. The market share of EVs and the total emissions in year 12 can be seen in Figure 15 and 16.

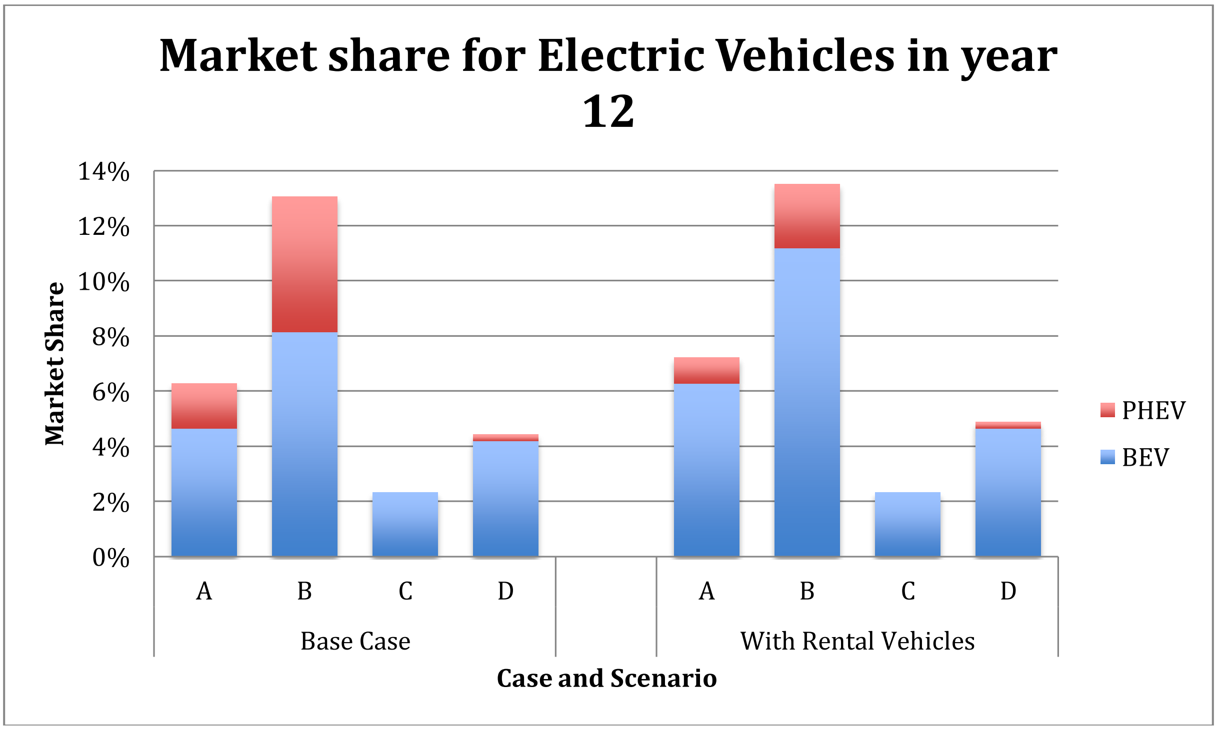

Figure 15: The market share for electric vehicles in year 12 for the four different scenarios.

The total CO_2 emissions will be reduced for scenario A and D when the amount of BEVs are increasing and the CO_2 emissions will be unchanged for scenario C when the market share of the different vehicle types remain unchanged. However, for scenario B there will be a small increase of CO_2 emissions. One reason for this is that the trips from rental vehicles will increase the emissions from gasoline. The major difference however, is that there is a transition from PHEVs to BEVs and to a smaller degree from diesel vehicles to BEVs, leading to an increase in the emissions from the production of the vehicles.

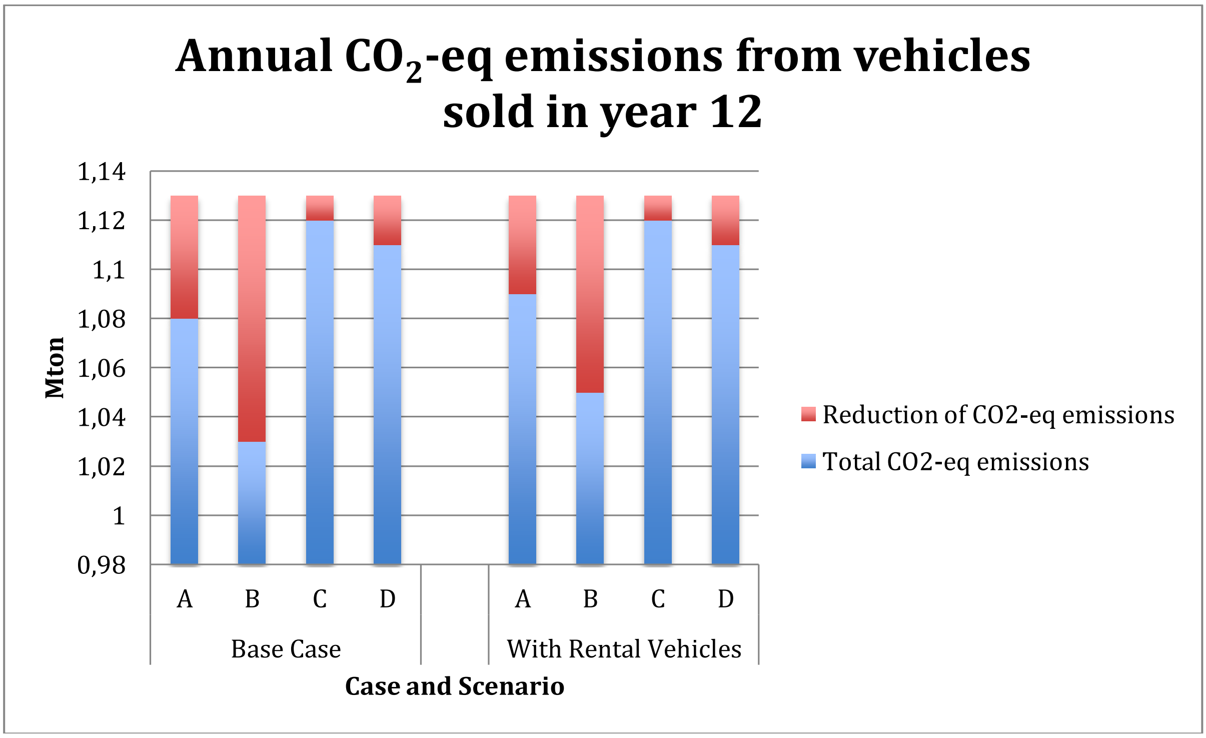

Figure 16: Total CO_2-eq emissions and the reduction of CO_2-eq for the option to rent a vehicle case.

3.7 Vehicle possession times

The model results change depending on the time a car-holder owns a car before a new one is obtained. For Base case a possession time of 8 years was assumed. A longer car-possession time should increase the amount of expensive cars and reduce the amount of gasoline cars because of the investment costs being divided over more years. The results are only shown for year 12 except for when a car possession time of two years is assumed. This is because the results for the other possession times in year 1 are very similar to Base case.

3.7.1 Two years possession time

The results when a two year car-possession assumption is made can be seen below in Table 28 and 29. A noticeable difference from Base case is the large amount of hybrid cars. This can be explained by the fact that the majority of the investment cost is returned when the car is sold, which combined with the 40.000 SEK subsidy for electric cars make them not much more expensive or even cheaper to buy than diesel and gasoline cars. This is also the reason why the annual emissions are so low. The reason there are few BEVs in the first years is because of the larger investment price difference between BEVs and diesel/gasoline cars, even when including the subsidy. This combined with the limited battery capacity of BEVs make them not as successful as hybrids. The total market share for electric vehicles will be 73.9-76.7%. The emissions reduction compared to year 1 in Base case lie between 46.0% and 57.0%.

Table 28: Market share and CO_2-eq emissions two years possession time-case for year 1.

Year 1	A	B	C	D
Gas [%]	37.30	37.30	40.56	40.56
Diesel [%]	24.48	24.48	36.13	36.13
PHEV [%]	37.30	37.30	22.61	22.61
BEV [%]	0.93	0.93	0.70	0.70
CO_2-eq [Mton]	0.84	0.84	0.99	0.99

Table 29: Market share and CO_2-eq emissions two years possession time-case for year 12.

Year 12	A	B	C	D
Gas [%]	9.09	5.36	11.89	6.29
Diesel [%]	7.69	7.93	14.22	14.22
PHEV [%]	67.13	70.63	63.87	69.46
BEV [%]	16.08	16.08	10.02	10.02
CO_2-eq [Mton]	0.50	0.49	0.61	0.58

3.7.2 Five years possession time

In this analysis, there are considerably less hybrids than for when assuming a two years possession time. This is because of the lower resale price of the cars is making the 40.000 SEK subsidy less significant, which make diesel cars more attractive than hybrids investment cost wise. The total market share for electric vehicles will be 5.1-20.3%. The CO_2 reductions are between 1.0% and 11.6%. Results for year 12 is presented in Table 30.

Table 30: Market share and CO_2-eq emissions five years possession time-case for year 12.

Year 12	A	B	C	D
Gas [%]	35.66	24.48	37.76	26.57
Diesel [%]	51.05	55.24	57.11	65.50
PHEV [%]	6.29	10.96	1.40	3.26
BEV [%]	6.99	9.32	3.73	4.66
CO_2-eq [Mton]	1.05	1.00	1.12	1.10

3.7.3 Eleven years possession time

Eleven years is the longest amount of time a driver is assumed to keep their current car in this study. The trend with decreasing market shares of BEVs and PHEVs in progressive longer possession times is now broken, since there are more BEVs in Table 31 than in Base case. This means a car-possession time of between five and eleven years has the worst impact on the number of electric vehicles and emissions. There is a higher amount of BEVs and diesel cars compared to Base case due to the fact that the investment costs are divided into more years. This decreases the CO_2 emissions by 1.1% to 10.3% during these twelve years compared to Base case. The total market share for electric vehicles will be 3.1-11.0%.

Table 31: Market share and CO_2-eq emissions eleven years possession time-case for year 12.

Year 12	A	B	C	D
Gas [%]	23.54	14.92	23.54	14.92
Diesel [%]	66.67	67.83	73.43	79.72
PHEV [%]	3.50	7.23	0.00	0.23
BEV [%]	6.29	10.02	3.03	5.13
CO_2-eq [Mton]	1.07	1.01	1.11	1.10

The electric car market share and emissions in year 12 are shown in Figure 17 and 18. Longer car possession times lead to primarily fewer hybrids. This is because of the lower resale price of the cars is making the 40.000 SEK subsidy less significant, which make diesel cars more attractive than hybrids investment cost wise. This is true also for BEVs but because of the limited potential for BEV, the decrease is not as apparent as for PHEVs.

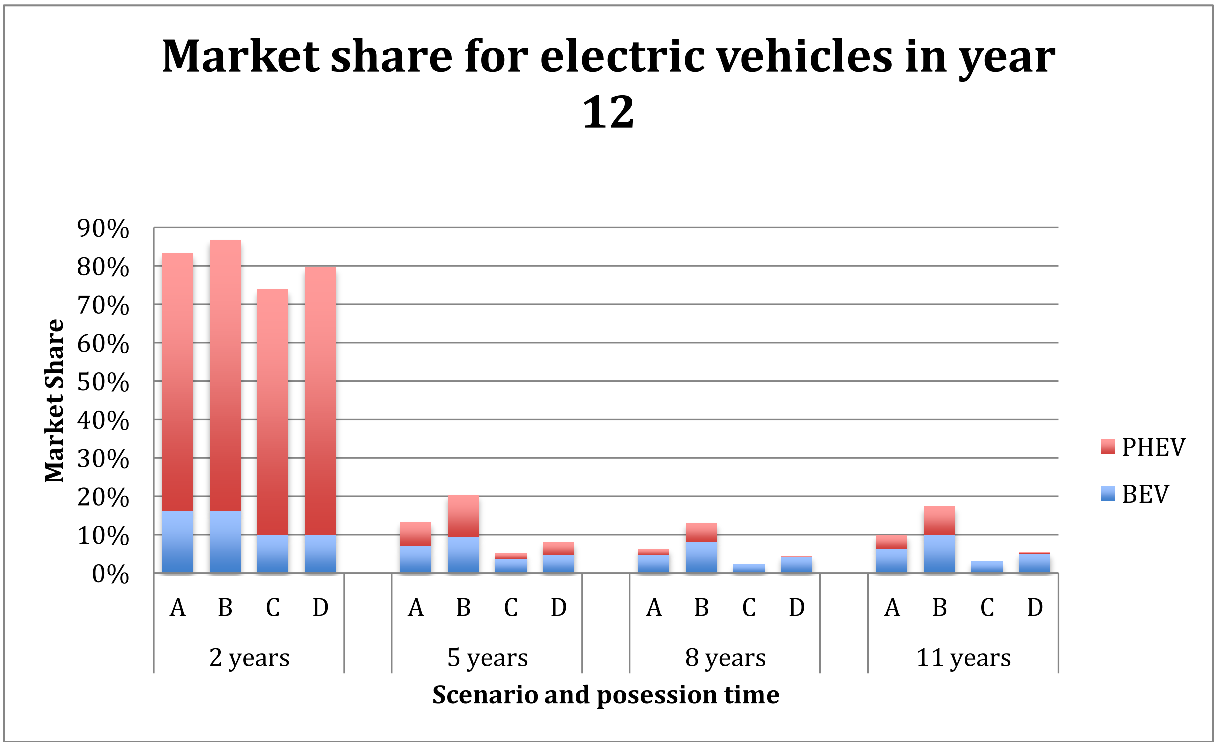

Figure 17: The market share for electric vehicles in year 12 for the four different scenarios and the different possession times.

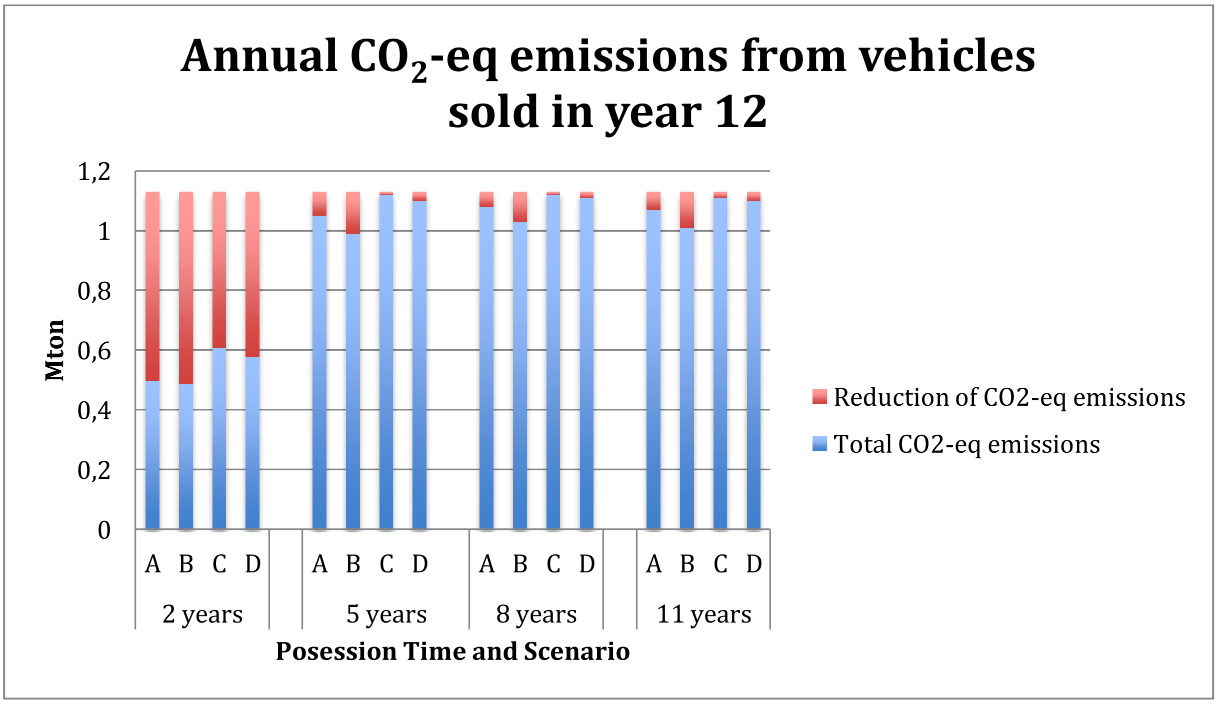

Figure 18: Total CO_2-eq emissions and the reduction of CO_2-eq for the vehicle possession time cases.

4. Discussion

In this study there is an assumption that users are investing in vehicles based on a *total cost minimization principle,* which might not always be the case. The price is probably an important factor when investing in a vehicle but very few buyers do calculations over the total ownership period to compare the cost of different vehicles. However, that users take the running cost of the vehicle into consideration when investing is probably true. Factors such as brand loyalty and status of the vehicles are other aspects that we have not included in this paper which might have had an effect on the results.

Because of the innovative and environmentally friendly nature of electric vehicles, some users are willing to pay more an electric vehicle compared to a conventional vehicle. This *willingness to pay more (WTPM)* is a measurement on how much individuals are willing to adapt to new technology. There is also a possibility that the WTPM for electric vehicles can be negative for some users since there are always skeptics for emerging technologies. Including this parameter could influence the future market share of electric vehicles. However, since there seems to be no previous data of WTPM in Sweden, and because of the difficulty of estimating these values without a wide scale questionnaire to the Swedish people, which is beyond the scope of this study, this parameter has not been included.

In the *used car movement database*, 429 cars have been logged over a period of at least 30 days. The number of logged cars may have been a large enough sample size but the number of large cars in the database is only eleven. This probably creates skewed results regarding the total Swedish market share when the proportion of large cars is higher in reality. The database thus should be much more accurate for only medium sized cars which make up for over three thirds of the cars. A logging period of 30 days is enough to capture the difference in driving distance throughout the week but not to show differences between seasons. The collection of data is however spread out over the years the logging was made, making this issue have less impact. Still, in future studies a longer logging period would be beneficial to have more accurate results. The electricity consumption of EVs during the winter is higher when electricity needs to be used for heating. This would affect the battery simulation results and would be interesting to have in the model to see how this would affect the results.

The chosen *vehicle sizes* of less than 1200 kg for small cars and more than 1900 kg for large cars seems to be a good approximation according to (Gnann et al., 2015). To obtain better results the number of vehicle sizes could be increased beyond three or even have a continuous car size model where the car properties are individually linked to each car depending on its weight.

Since it is assumed that all electric cars can be charged in homes by electric vehicle chargers, it is fair to assume that a *minimum charging time* of ten hours is possible without additional charging stations. When a four hour minimum charging time is assumed, workplaces are required to give access to charging stations which will often result in extra costs. Neither the chargers at home nor at working places are considered in this study and could be a possible expansion of this work.

In the model we have used a *discount rate* of 5% for evaluating the time value of money. From tests in the model it has been seen that this parameter have a large impact on the results. The time value of money is very different for different users and to get a better result the discounting rate would have to be studied in greater detail.

One interesting continuation of the study would be to take a deeper look into the *driving patterns* of the users. There is a difference in fuel consumption between the drivers' driving behavior and between those that are driving inside or outside of a city area. A driver that accelerates more often and has a higher average speed should have a larger average fuel consumption of the vehicle. Another expansion to this study could be to include a price elasticity of the driven vehicle distances. It is assumed that driving patterns remain the same even when the fuel prices increase. Rejecting this assumption should give more accurate driving distances when the fuel prices increase each year.

A larger number of electric vehicles leads to a higher *electricity demand* which may increase electricity prices. However, as demand goes up, more companies will be willing to build new power plants to meet it. The demand increases slowly over the years which should give electricity producers enough time to increase production. Also, electric vehicles are able to benefit further expansion of intermittent renewable energy with lower electricity prices by providing energy storage when the cars are connected to the electric grid. When there is an overproduction of electricity, the excess energy can be stored in the batteries and later be used to supply electricity when production goes down.

From the results a conclusion can be drawn that electric vehicles will penetrate the market in the future on a higher level than today. When *the market for electric vehicles* grows larger there is a possibility that the price reductions might be even larger from such factors as learning by doing and economy of scale. On the other hand, the annual battery cost reduction of 8% may not be able to be sustained and could be less in the future.

The model shows a high potential to reduce emissions by *increasing fuel taxes*. The number of electric cars in the model is increased by roughly 30% each time the fuel tax is increased by 50%. This indicates an almost linear relation between the conventional fuel price and the calculated number of electric cars where a 20% conventional fuel price increase leads to 30% more electric cars, since the fuel tax is around 40% of the total fuel price. For an extreme tax increase of 150%, the total CO_2 emissions would be reduced by 2.8% to 24.1% in year 12 depending on scenario. From a political standpoint it would be hard to implement an increase of the fuel tax by 150% at once (which would increase the fuel prices by roughly 60%). The increase could however be gradually implemented by increasing the taxes by around 8% per year for twelve years. Even this could however be problematic to implement, considering the fuel prices have been relatively constant for most of the last fifteen years and because the gasoline and diesel prices in Sweden already are among the highest in Europe (Motormännen, 2014). It would be easier to defend a tax increase of 50% or 100% with less reduction in total emissions, while still leading to considerably lower emissions compared to Base case.

In the model we have assumed a *current oil price* of $106 per barrel, based on data from 2013. However, the oil price during the time this study was made lied around $45 per barrel. This indicates a high uncertainty of the current oil price, which has a large impact on the results from the model. This can be seen in the results regarding the fuel tax increases, except the oil price has an even more impact than the fuel tax. However, the chosen oil price has been true for the past five years and has been declining only for the past year.

Since the *electricity price* is low in Sweden due to a very large share of power sources with low running costs, it was assumed a change in electricity price would not influence the results in a significant way. Thus a case was made to investigate whether the price of electricity had any impact on the results. The price plays however a greater role in the results than expected.

While an unchanged electricity price allows some electric cars to have entered the market in year twelve, they are almost completely removed if the electricity price would increase by 150%.

From the results it is hard to draw any exact conclusion about how much of the progress that should go to *reduce the price of the battery* and how much that should go to *increase the capacity*. The model shows that PHEVs benefit to a higher degree from increasing the capacity than BEVs, but also BEVs seems to benefit the most when not all of the progress goes to decreasing the battery price. The reason why PHEVs benefit to a larger degree from increasing of the capacity than BEVs is probably that when the capacity is increased a larger proportion of the driving can be accomplished with electricity. That will lead to a decrease of the running cost, and the decrease of the running cost based on larger battery capacity seems to in the end have a larger effect on the total price than decrease of the battery cost. For BEVs the effect when increasing the battery capacity is that more drivers can change to a BEV without changing their driving patterns. However, such a change will lead to a higher total cost when the investment cost is increased and the running cost will remain unchanged.

To maximize the total amount of PHEVs it seems that the best way is to put all of the battery development to increasing the battery capacity. However, an equal development towards battery cost reduction and size increasing seems to be the best way to increasing the number of BEVs when taking all the scenarios into consideration. When looking into how to maximize the total numbers of electric vehicles the results are very dependent on scenario. For scenario A it is C25/P75 that will maximize the total number of electric vehicles and for scenario B it is C75/P25. For scenario C that is the worst scenario in this study, the market share of EVs will always lie around 2%. For condition D C100/P0 is the best way to maximize the total number of electric vehicles. The best way of using the battery progression to reduce CO_2 emissions according to the model is to use a maximum development towards battery capacities. The main reason this is the best course of action in this case is because in the model it increases the amount of PHEVs the most and PHEVs have in the emission calculations lower emissions during production compared to BEVs. However maybe the emissions from production should be increased when the capacity for the batteries is increased. This has not been considered in the model.

The size of *electric car subsidy* seems to have a significant effect on the number of both BEVs and PHEVs. Every time the subsidy is increased by 10.000 SEK the number of electric cars in year twelve in the model is increased by around 50%. This holds true until a subsidy of 70.000 SEK when electric cars become the majority in the Swedish car market. This is because the subsidy lower the investment cost of EVs while the resale price remains the same. Raising the subsidy with 10.000 SEK gives a larger increase of electric vehicles than raising the fuel tax with 50%. This is due to the much higher investment price being the largest barrier for electric vehicles. This means an increased subsidy would in this model be preferred to implement over a fuel tax increase. It is also possible to finance increased subsidies by increasing fuel taxes, thus combining the two policies. If the electric car subsidy would be increased to 70000 SEK from 40,000 SEK as suggested in (SOU, 2013), the calculated emissions from the bought cars would in year 12 be decreased by 10.1% to 32.6% at a cost of 1.34 to 3.38 billion SEK. Compared to the annual expenses of the Swedish government of 891 billion SEK in 2015 (Sveriges Radio, 2014), this may or may not be a large expense.

From a purely economic point of view it can be seen in the results that *a possibility to rent a vehicle* for longer trips could increase the number of BEVs in the future. This is especially true for scenarios with better possibilities to charge the vehicles. There is however an additional cost for this option: the users might feel that the money saved by renting a vehicle every time they are not sure if the capacity is sufficient is not worth the extra effort needed. This aspect is not included in the model and would maybe decrease the amount of electric vehicles in the results.

It could be assumed that a longer *car possession time* would increase the market share of electric cars due to their high investment costs, but the results show that the highest emission savings would occur if consumers kept their cars for only two years. The electric car subsidy of 40.000 SEK combined with a high resale value make these cars very cheap to buy, even to the point of being cheaper than diesel and gasoline cars. When the cars are kept for the maximum assumed number of years (eleven), the emissions are lower than if eight years are assumed. This is because of investment costs being spread out over a larger number of years, which makes cars with low running costs but high investment costs more attractive. Changing the car-holding time also changes the cost of subsidies for the government because of more frequent car purchasing.

The fact that the number of electric cars and total emissions are higher for both a five and a eleven year long car-holding time compared to the eight years assumed in Base case suggests that there is a certain number of car-holding years between five and eleven where the market shares of EVs will be at its maximum.

Unfortunately, one cannot draw any certain conclusions from this case because of the uncertainty of input parameters. The market of used BEVs and PHEVs have not developed into a large scale yet thus making the assumed value of resale price highly uncertain. This combined with large variances of results between different assumed car-holding times indicate that this parameter highly influences the results for being so uncertain. This case also has not taken changes in the used electric car market itself into account. It would be harder to sell a used electric car than a used diesel or gasoline car due to not getting the subsidy. In addition, if a large number of electric cars are bought and later sold, the used car market will be saturated of electric cars, which will reduce the resale price even more. Some may also buy an electric car, get the subsidy from the government and resell the car for profit, which would saturate the market even faster.

5. Major findings

Based on the environmental policies investigated and the used levels of subsidy and fuel tax increases, the most beneficial policy in this study to promote electric vehicles is subsidies. It has been calculated to have a high potential of increasing the number of EVs in the car market when the high cost is the largest barrier and it does not require any large infrastructure investments such as investing in supercharging stations. The only barrier is the cost for the subsidies itself. This may however be at least partly financed by a higher fuel tax which would increase the number of EVs further. Even if subsidies cost the government money while fuel taxes generate money, it has been assumed that a 10.000 SEK subsidy increase is easier to implement than a 50% fuel tax increase. Another conclusion is that policies that are focused on reducing the investment cost of EVs lead to a larger electric vehicle market in the model than those that are aimed to reduce their running costs.

From the results it seems that increases in battery capacities are more beneficial to the electric car market than reductions of battery prices. In the model, PHEVs become more economic attractive the more focus there is on increasing battery capacity, and BEVs benefit the most from an equal development of battery capacity and cost. This means increasing battery capacities seems to be as important, if not even more important than decreasing their costs.

A conclusion from the results in Base case is that the possibilities for charging the vehicles were more important for the results than the development of the oil price. It seems therefore that one of the important aspects for increasing the amount of electric vehicles is for the businesses to provide charging opportunities for their employees. These costs are not considered in this study and could be a possible expansion of this work. Another important aspect might be to support infrastructure investments in superchargers.

At the start of this study an assumption was made that the electricity price would have a minor impact on the future market share. However the results proved this assumption to be wrong. It was assumed that the price of electricity in Sweden is low enough to justify a constant electricity price as a good enough approximation of reality. Instead, a variable electricity price should have been used where the price is highest during the winter and lowest during the summer.

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