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Environmental assessment for the whole EV life cycle

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Executive Summary

The current idea of electric vehicles is based on environmental targets. EVs are seen as a solution to reduce car traffic environmental impacts, especially green house gas emissions. In this work the life time environmental impacts of EVs are studied in a time scale to year 2050.

European union has set green house gas emissions targets for years 2020 and 2050. The base target is to reduce emissions counted from the reference year of 1990. For 2020 the target reduction is 20 % and for 2050 the reduction is 60–80 %. In year 2009 individual reduction targets for each member state was agreed. Reference year was 2005 and the target for Finland is set to 16 % reduction at 2020.

There are long term statistics in Finland about car usage. The base of this study is to estimate the future car usage based on the population development. The statistics indicate that the driven kilometres correlates to per capita behaviour, not to the car density. But the car density is important for the impact of car manufacturing.

A special question in Finland seems to be the current long life time of cars. As EV batteries are expected to have a 10 years life time, that is assumed to lead to the life time of an EV to be also 10 years. That is roughly half of the current 19 years car life time. This has a remarkable effect to the car sales volumes in Finland.

Heating is another matter which seems not to be an important problem in international EV development, though the air conditioning is discussed as an energy consumer of an EV. If an EV is fitted with an heath pump based HVAC-system, heating and cooling represent 8,2 % of the annual energy consumption of an EV in Finland.

The green house gas emissions of an EV are practically the emissions of electricity production. This applies for both manufacturing and using the EV. The importance of manufacturing is high with EVs, when manufacturing emissions may be 25 % of the life time emissions.

The main focus of impacts are for short term. For long term up to 2050 there are many uncertainties. For short term the combustion engine car will be dominant and the EVs as car concept are similar to combustion engine cars. This leads to the situation, where other car traffic impacts than emissions remain unchanged.

Car traffic emissions were studied in four scenarios. The base scenario kept practically everything unchanged but EVs entered to car markets and their share was estimated to grow like a new car model. In other scenarios various actions were made to reduce car usage and unit energy consumption. Also the electricity production and combustion engine fuel technologies were assumed to develop towards smaller unit emissions.

The base scenario does not fulfil the EU emission targets nor in short neither in long term. EU long term targets are possible to gain with parallel actions besides EVs to enter to market. But the short term target for 2020 is difficult without a strong control of the emissions of other cars than EVs. That may happen by limiting the import and sales of fossil fuels to the EU emission target level.

To gain the emission targets requires to reduce the need to use car. Realistic actions are to improve public and delivery transport, reduce the emissions from electricity production and replace fossil fuel with reduced emission fuel technology. All these actions are necessary in addition to use EVs.

EVs are not the solution to reduce car traffic emissions in short term and to year 2020 targets. It is impossible to replace combustion engine cars fast enough. For long term EV is the solution for car technology and have even more potential than other propulsion technologies. This is because EV technology makes possible to develop light and personal vehicles which gives growing freedom to urban and living environment design.

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List of Acronyms and Abbreviations

°C	Degrees Celsius
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
CO_2-eq	CO_2-equivalent green house gas emission
CV	Combustion Engine Vehicle
€	Euro Currency
E-REV	Electric Range Extender Vehicle
EU	European union
EV	Electric Vehicle
g	Grams
g/s	Grams per Second
GDP	Gross Domestic Product
GHG	Green House Gas
HEV	Hybrid Electric Vehicle
HVAC	Heath, Ventilation and Air Conditioning
ICE	Internal Combustion Engine
kgs	Kilograms
km	Kilo Meter
kW	Kilo Watt
kWh	Kilo Watt Hour
L	Litre
L-EV	Light Electric Vehicle
Li-Ion	Lithium Ion
LPG	Liquefied Petroleum Gas
m^2	Square Meter
m^3	Cubic Meter
MJ	Mega Joule
Mkg	Millions of kilograms
MW	Mega Watt
P-EV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
RE-EV	Range Extender Electric Vehicle
TWh	Tera Watt Hour
VAT	Value Added Tax
W/K	Watts per Kelvin

1. Introduction

1.1. Scope

The current idea of electric vehicles is based on environmental targets. Road traffic currently uses only fossil fuels and practically only oil based products. Few exceptions, like trolley buses, biogas buses or the use of alcohol as car fuel as in Brazil, are too small share of all driven kilometers and their impact is not seen in emission statistics.

Though electricity in a vehicle removes exhaust and CO_2 emissions of a single vehicle, there still is the need to produce the electricity. In the previous reports of SIMBe project there is already seen, that to only switch from combustion engine to electric engine and a battery, does not fulfill CO_2 emission reduction targets (Alku & Kosonen 2011a). There must happen something else too, as reduction of CO_2 emissions in electricity production, reduction of energy consumption of a single vehicle, reduction of travelled kilometers or a change in modal split. Or some combination of all these.

In this report the future of EVs environmental impact is studied through a combination of scenarios in different partial fields of development having an impact to EVs environmental impact. The study is mainly limited to the EVs energy consumption and production. One reason for this is, that information about the environmental impact of the EV and it's battery production is still uncertain as there is no large scale production experience available. One background for this is the uncertainty of battery technology future and availability of some key raw material like lithium.

1.2. Industrial challenges

International automotive industry seems to be slow to enter to EV market. Trend of year 2011 seems to be hybrids that include both combustion engine and electric technology. By means of an idea that EV is simpler and therefore cheaper than a complicated combustion engine vehicle, shifting towards hybrids is a drawback. Instead of one propulsion technology, hybrid-EV has two technologies and double production cost.

Hybrid is understandable by means of industrial facilities in vehicle industry. The interest of industry is to be able to use the existing machinery and tools and not to have to re-invest in tooling in a short period. With hybrids, industry has use for both old combustion engine based production technology, and new EV technology production can be extended slowly and with moderate investments.

This situation may become a competitivity problem for old vehicle industry. The local industry in growing markets like Asia and India do not have the load of old factories. The growth in markets may be covered with new EV production capacity. Then this industry does not have cost load of old investments and may then be very competitive in selling EVs to European, US and Japanese markets. Taken into account that old vehicle industry already has lost it's power because of the saturation of car density in the industry's domestic markets, there may happen similar structural transition as has happened already in many industrial fields: production of mass produced consumer products moves to Asia and India and other developing areas.

Keeping the above in mind, it seems not to be a good idea for the old vehicle industry to try to slow down the shifting from oil based technology to EV technology. Old industry may keep their market share only if they can be competitive against growing new industry. Instead of trying to brake down the shifting with products like complicated hybrids, industry should widen it's product from only the vehicle to accompanying services that make the shifting easier for the customer. These additions may also protect the industry against competition of low production cost. The advantage of local industry is to be able to offer something that cannot be imported from very far away. Which is products that are required to implement EVs to urban structure and after sales services that must be produced locally.

To run car sharing, leasing or partial leasing like selling the vehicle but leasing batteries are also business ideas to speed up the shifting from oil to electricity. Charging infrastructure does not exist yet so there is open market for battery leasing technologies. They may also lower the threshold of a customer to shift over to EV. By leasing at least the battery, the customer do not need to bound himself to new, expensive but possibly soon outdating technology.

1.3. Objectives

There are great expectations put to electric vehicles. On the other hand EV is considered as a solution to all the drawbacks of current car use and a technology that may reposition car as a dominant and future mobility mode. Another approach is that electric vehicle is only a choice of a propulsion technology that may not alter anything but local emissions combustion engine cars have.

In this work the main focus is to find out how and in which time span the benefits of electric vehicles may be gained. The method is to combine scenarios of certain actions and possible future development estimates. The aim is to fulfill green house gas limits set by European union.

2. Overview of EV life cycle impacts

2.1. General approach

The main focus of EV benefits against combustion engine cars is the low CO_2 emission level of an electric driven vehicle. Though the actual emissions are fully dependent of the electricity production technology, EV still has the option to operate without local emissions and with zero emission from driving energy. And this is a significant benefit compared to combustion engine car, as the life cycle emissions of a combustion engine car are 75 to 85 % generated from the fuel (Gauch e.a. 2009).

To compare the life cycle of a combustion engine car and EV, the key factor with EV is the environmental load of the manufacturing. If an EV is similar to a combustion engine car, the difference is in the environmental load of combustion engine and mechanical drive train compared to the load of battery and electric drive train including electric motors and power control units. Roughly it is estimated, that electric drive train and combustion engine and it's drive train has similar environmental load. Then the load of battery is extra compared to combustion engine car (Gauch e.a. 2009, Samaras & Meisterling 2008).

The current problem in estimating the environmental load of a battery is, that batteries are not manufactured and recycled in such a large scale as would be the situation when EVs have equal market share and production numbers as combustion engine cars today. The refinement or recycling of the minerals are energy intensive, so the electricity production emission profile is crucial for the battery manufacturing in future too, but there is no experience of the energy consumption in large scale battery recycling.

The methodological problem in estimating the life cycle impact is, that a car's or EV's life cycle is too long to keep the factors constant. The life cycle of a car in Finland is 19 years, and significant development in energy industry should happen during same time. Also the past development cannot be kept valid to extrapolate to future. For example the environmental load figures reported for car manufacturing varies within similar products. The information is based on the calculations by manufacturers and are dependent on the location of the factories and technologies used (Kujanpää 2008). To estimate the future manufacturing load requires to estimate how and where manufacturing will develop and grow.

In this situation, the method to estimate EV's environmental impacts is based on a set of scenarios. The scenario approach must also be included in the initial values used in manufacturing impacts.

2.2. EU targets for green house gas emissions

European union decided it's climate strategy at 17.12.2008 in European parliament (COD(2008)0014). The EU target is to reduce green house gas emissions, including road traffic CO_2-equivalent emission, 20 % from the 1990 level to the year 2020.

European council gave it's decision 407/2009/EC for green house gas emissions at 6.4.2009 (EU 2009). This decision is for years 2013 to 2020 and the emission limits set by country are referred for year 2005. For Finland the reference rate is 16 % reduction compared to year 2005 emissions. At the starting year 2013 emissions shall not exceed average annual greenhouse gas emissions during 2008, 2009 and 2010. The reduction to year 2020 shall be linear starting from 2013, including by making use of the flexibilities provided for in the decision.

The decision includes also a 60 to 80 % reduction target to the year 2050. Finland's own climate policy has set 80 % aim for 2050 (Valtioneuvosto 2009). For Copenhagen climate conference in 2010 EU released a plan to increase the 2020 target to 30 % if other large polluting countries would agree same level (EU 2010). This has not happened.

In Finland Ministry of Transport and Communications published 2009 a climate policy programme for 2009–2020 based on the EU climate policy (LVM 2009). In this programme an aim for 2020 is set to 11.4 million tonnes for the whole traffic sector including road, rail and sea. The aim is set to be 15 % of the green house gas emissions without any actions to limit them. Comparing this to traffic sector green house gas emissions in 2005, 13.5 million tonnes, the published aim is 15.6 %. In the policy program, most of the reduction, 2.1–2.4 million tonnes, is from car traffic.

Total CO_2-equivalent emissions from traffic were 12.6 million tonnes in 1990. To reduce this by 20 % ends to 10.1 million tonnes.

Total emissions in Finland were 56.97 in 1990 and 57.04 million tonnes in 2005 excluding reduction caused by forest industry and land use. They reduced emission by 21.40 and 31.00 million tonnes (Tilastokeskus 2007). Total emission increased from 1990 to 2005 with 0.12 %. Traffic sector increase was 7.1 %. This means, that the aim set for traffic sector in Finland is less than for the other sectors where decrease has happened already.

The ministry policy for traffic is slightly less than the average aim for Finland from reference year 2005. The EU rule is for total emissions from a member state, so it is domestic decision to allocate the reduction inside a member state.

As seen from above, there are two baselines for setting the EU target, years 1990 and 2005. Driven car kilometres in Finland in 1990 were 33.4 billion (Liikennevirasto 2010) and CO_2-emissions were 6888 million kilograms (Lipasto 2009). For year 2005 kilometres were 44.2 billion and CO_2-emissions were 7200 million kilograms.

To follow the base of the EU policy, in this work the reference emission level is set to the 1990 emission values for traffic in Finland and the original 20 % decrease is used. From this reference level the targets are:

- 5500 million kgs. in 2020.
- 1380 million kgs. in 2050.

The starting value was stated to be the average from years 2008–2011, which is 7189 million kg. As this is already exceeded, the above mentioned targets are interpreted so, that emissions must decrease in linear manner from 2012 level to 5500 Mkg in 2020 and then to 1380 Mkg in 2050. Figure 1 displays CO_2-emission EU goal and estimate of car traffic emissions of car use estimate in this work with fossil fuels.

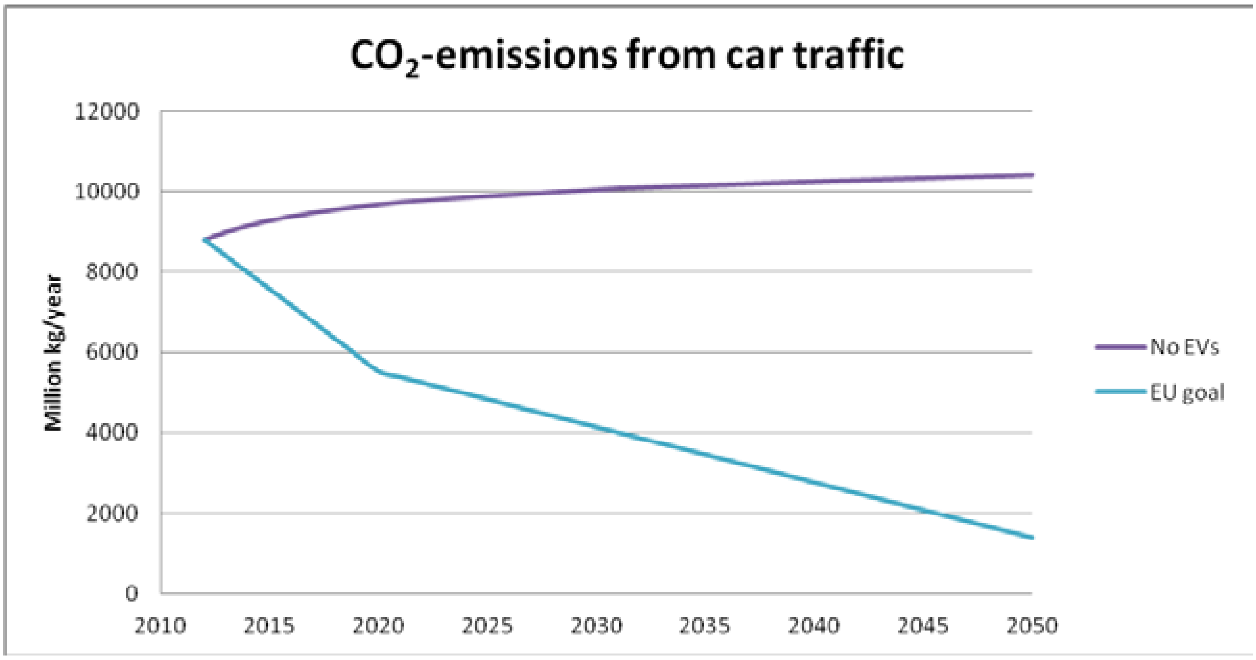

Figure 1. CO_2-emission target according to EU and comparison to car traffic emissions with fossil fuels.

2.3. Population and car density

Environmental load of cars is bound to population and car density. The population development of this work is based on the estimate of Tilastokeskus (Statistics Finland), which ends up to 6,1 million inhabitants in 2050.

Number of cars is calculated from population through car density. Long term statistics seemed to set car density to app. 400 cars per 1000 inhabitants. Anyhow from 2005 car density has grown constantly app. 3 % per annum being 535 in 2010 (Figure 2). In the ministry climate policy car density was set to grow to 550 (LVM 2009). The ministry policy was written in end 2008 and therefore based on old information from today's point of view. That's why the estimate in ministry policy is dismissed. In Germany car density is app. 600 and in USA app. 800. Internationally car density correlates to GDP per capita (Heymann 2011).

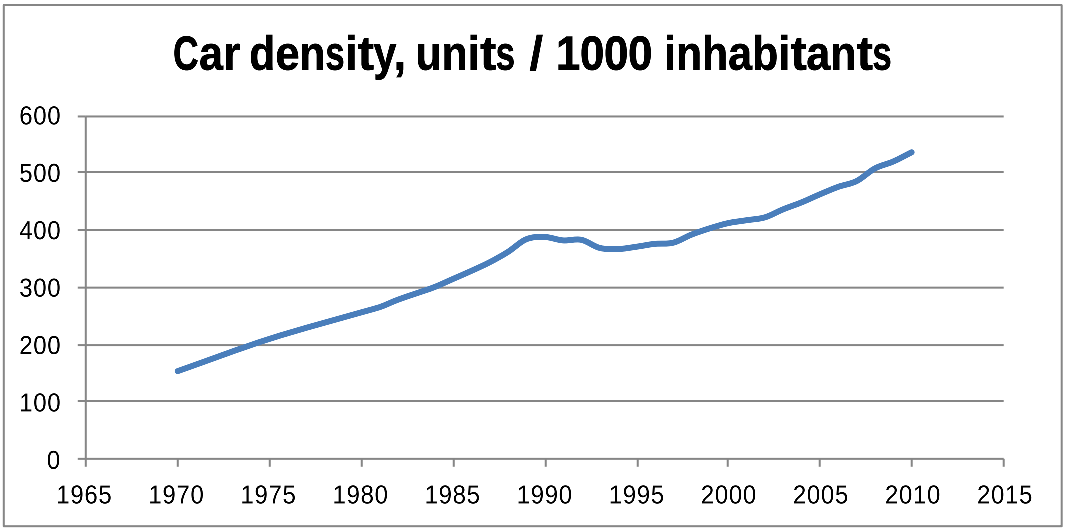

Figure 2. Car density development in Finland 1980–2010. Data source Tilastokeskus (2011).

It is understandable, that car density will not grow to infinity. One practical limit to car density could be the population share of those that may have a driving licence. In Finland Tilastokeskus has published an estimate of the share of age group 15–64 years. This share decreases from 66 % in 2010 to 57% in 2050. The car density of USA, 800, must be higher than the share of suitable age group, but this is usually explained by people having cars for different purposes. German car density corresponds to population age share.

Though car density grows, the general experience is, that car usage per car decreases (Figure 3). The simple explain is, that one driver can drive only one car at the time. With low car densities lack of cars limit the driven kilometres, but with high densities the time and need to travel limit the driven kilometres. In Finland the driven kilometres per person still has grown, but it varies more by home location than by development over time (HLT 2006, Strömmer e.a. 2010).

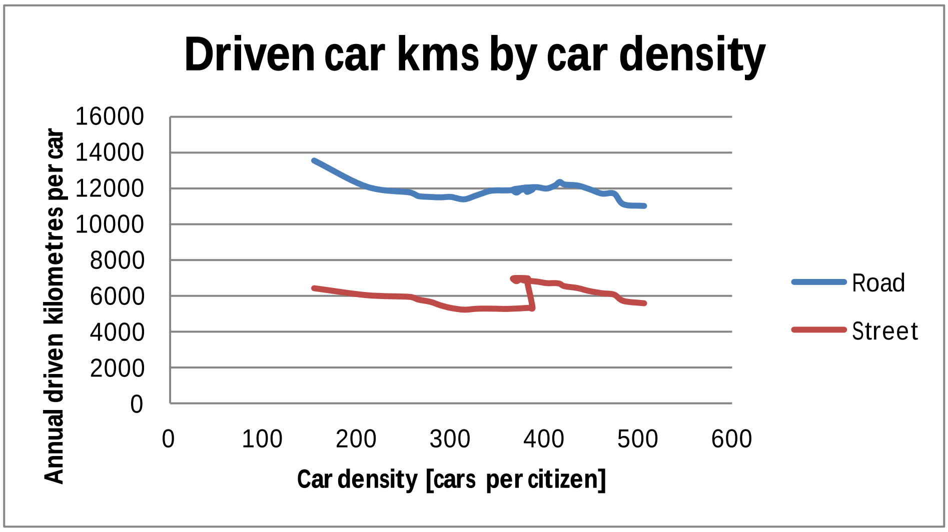

Figure 3. Annual driven kilometers by car density in Finland between years 1975–2009. Data source Liikennevirasto (2010).

By means of environmental impacts caused by using cars, car density is only remarkable if it limits car usage. Therefore car densities over the density of driving licences is negligible for impacts from car usage. Car densities over driving licence density is remarkable for the environmental impacts from car manufacturing if car density is filled buying new cars, not extending the life time of cars. When discussing about EVs which are new products and which start to reach their life time only after at least 10 years, it seems not sensible that they might increase car density either extending the average life time of cars being bought for any other purposes than continuous use.

Another question is electric vehicles which are different than current combustion engine cars. For example devices like pedelecs and Segway, which may become usable for all people and do not require a driving licence. But these are not counted into car density, though they are a part of traffic system and alternative for car ownership.

In this work car density is set to grow to 600 with decreasing density growth being 3 % in 2010 and the growth decreases 27 % per year. With this development car density reaches 600 in 2030 and remains then constant (Figure 4).

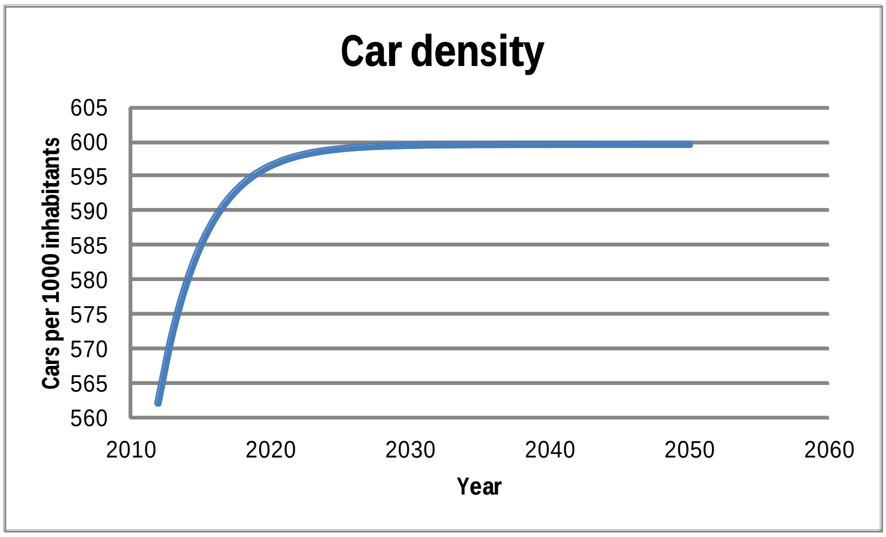

Figure 4. Car density development curve.

2.4. EV categories

In the second phase of this SIMBe work package was more detailed discussion about the EV technologies and their share of cars. The discussion was based on Helsinki region mobility statistics in which the use of a car can be seen more precisely. The main point was, that daily car use is suitable for relatively short operating range of a plug-in only EV, but holiday and week-end use require a range extender or other kind of a hybrid solution (Alku & Kosonen 2100b). This leads to the solution, in which a single car household buys a hybrid and two or more car households may buy a plug-in only EV for the second and next cars.

For this work it is worth for to discuss a bit more about EV technologies. By means of reducing emissions in large scale, any hybrid vehicle must work mainly with charged electric energy. The role and construction of the combustion engine must be a range extender, which in practice means, that the continuous power is designed for moderate speed at Finnish highway operating. This way the range extender unit is small enough not to limit vehicle capacity and weight. Also this way the range extender unit may be a combined heater unit too saving to install a separate heater unit into the vehicle.

In this work EVs are classified into three categories:

- **P-EV** is *plug-in only electric vehicle* which is used mainly for daily one person urban area travelling. Operating range is 100–150 kms and the average tare weight is remarkably less than 1500 kgs usual for current 5 persons combustion engine cars. Annual kilometres are 18 000.

- **RE-EV** is *plug-in electric vehicle with range extender* for continuous long distance travelling. Range extender unit is used for heating too in which mode it also charges batteries. Operating range with battery is 100–150 kms which is used mainly for daily one person urban area travelling. Average tare weight is 1500 kgs as is usual for current 5 persons combustion engine cars. Annual electric kilometres are 13 000 and combustion engine kilometres are 5 000.

- **L-EV** is *plug in only light electric vehicle* designed for personal use in urban area. Size and performance are less than what we understand as a car today, but the vehicle is suitable for any weather condition use. Tare weight is less than 400 kgs. Energy consumption per kilometre is 0,12 kWh which is 60 % of normal EV. Annual kilometres are 6 000.

The share of these categories in EV fleet and sales is based on car numbers in households. The base assumption is that EVs bought to one car household are ER-EVs, which is 44 % of EVs according to the car ownership statistics. 46 % of cars are owned in two car households. Base assumption is, that the first EV is ER-EV and the second one is P-EV. 10 % of cars are in households having more than 2 cars. In these households third and more cars are assumed to be L-EVs. This ends up to the following share of EV categories:

- RE-EV 71 %
- P-EV 26 %
- L-EV 3 %

According to the above specified annual kilometres, 80 % of EV-kilometres are driven with charged electricity and 20 % with fossil fuels in RE-EVs. The share of L-EVs kilometres is only 1,1 %.

2.5. Life time of EV

Long time experience of a life time of the cars in Finland is near 20 years. The idea of a suitable lifetime of a car by automotive industry or by experience from other European countries is much less. In EU the life time is 10–15 years (Kanari e.a. 2003).

The long life time in Finland may be explained by the high prices of cars. Cars are used to the end of their technical life span. Better quality of new technology does not shorten the life time, because the benefit of better fuel economy or lesser repair cost does not cover the investment price to buy a new car. This can be seen also by calculating the optimal life time of a car in Finland. In some cases it is not economical to change the car ever, if the technical life time would be infinite (Kujanpää 2008).

The technical life time of a current car is limited by overall condition and damages in parts that are not meant to be serviceable or replaceable. Such parts are difficult to buy to old brands and may be too expensive compared to the market price of an old used similar car. Similar part in EV is the battery, that has short life time, 10 years, compared to the car life time in Finland.

Current value of the battery is half of the EV price. After 10 years the battery price may be much less, but state of the art battery technology may not be compatible. The situation may be similar to that of current battery operated commodities. When the battery wears out, the device will be thrown away. A new one offers plenty of new features with only marginal price over the replacement battery price.

In this work the EV life time is set to 10 years. This is based on the battery life. For the customers point of view, it is not interesting idea to invest for a new battery that may last another 10 years, which still is not the estimated remaining life time of the rest of the EV. To buy a new battery is not interesting idea even for the second hand EV buyer. Second hand cars are bought for low price and a possible readiness to service and repair the car by oneself. To pay a high price for a new battery does not fit into that idea.

The only possible reason an EV life span would be more than the life span of the battery is, that batteries are not a permanent part of the EV and batteries are leased or swapped within charging. This seems not to be trend of the manufacturers. Also the leasing availability of technically old batteries may not come true after 10 years from release of the battery models.

2.6. Car life time and car sales

Car sales is counted from the number of registered cars. During recent years car sales in Finland has been app. 110.000 cars per annum. As the number of private cars in 2010 was 2,9 million, annual sales does not fit to the life time statistics of 19 years. Based on statistics, car sales seems to be bound to economic trends. Therefore the annual car sales in this work is calculated from the average 19 years current life time of cars. For combustion engine cars the long term average of annual sales should be 147 000 in 2010. This corresponds to 5.3 % of car fleet is to be renewed annually.

The development of car sales depends on population growth and car density growth, if car use and ownership behaviour remain as is today. In case of strong shifting towards EVs, technology may have impact to mobility behaviour, car density and car life time. Anyhow as long as the share of any kind of EVs is small in traffic system, EVs cannot change general mobility behaviour. This is because the street, road and other artery network must remain suitable for traditional vehicles. It may be so, that there is some threshold EV share value which may start a strong and fast evolution in artery network.

The sales of plug-in EVs is still an open question. This question was discussed already in the first phase of this SIMBe work package. For energy production there was an assumption that EV sales could grow from zero to 100 % of new car sales in 12 years (Alku & Kosonen 2011a). In ministry's climate policy car sales was expected to grow to 7 % of car fleet because of new technologies (LVM 2009). This corresponds to over 200 000 cars annual sales, including both EVs and other cars. Based on published estimates and the development in car industry during last 12 to 24 months, it seems that the share of plug-in only EVs may remain to 25 % of car sales at 2050. But besides that, plug-in hybrid EVs using petrol or diesel engines may have 30 % share of sales.

The share of sales of all three EV categories described in chapter 2.4 is targeted to be 60 % of car sales in 2050 in this work. It is not specified in this work which is the technology of the rest of the sales, as the scope in this work is to estimate the environmental impact of the EVs. The earliest possible large scale availability of these EV categories is expected to start in 2014. This is based on the practice, that car industry usually demonstrates new concepts a pair of years before series production.

As is explained in chapter 2.5, EV life time is expected to be shorter than combustion engine car life time. As car density is not expected to lower because of EV technology, for certain share of EVs in car stock EVs must be sold more than combustion engine cars after the first EVs encounter the end of their life. As it seems to be, that international estimates of EV market share does not take into account any difference between the life times of EVs and combustion engine cars, the above mentioned market share of 60 % in 2050 is considered as equivalent to combustion engine car sales share. As an example, if EV life time is 10 years and combustion engine life time is 19 years, same share of cars in use require 1,9 times EV sales.

Market share is one of the main scenario variables in this work. The key question is, how EV market share may grow. Based on statistics, one popular car model represents few per cent market share (Autoalan tiedotuskeskus 2011). The most popular models sell app. from 1500 to 6000 units per annum (Figure 5). New models seem to start from annual sales of few hundreds up to one thousand and then grow quite rapidly like with 500 to 1000 more sold units per annum during few years. Then a model in static market position seem to have strong fluctuation, like the 2010 market leader Volkswagen Golf which varies between 3800 and 6400 during the focused 6 years period.

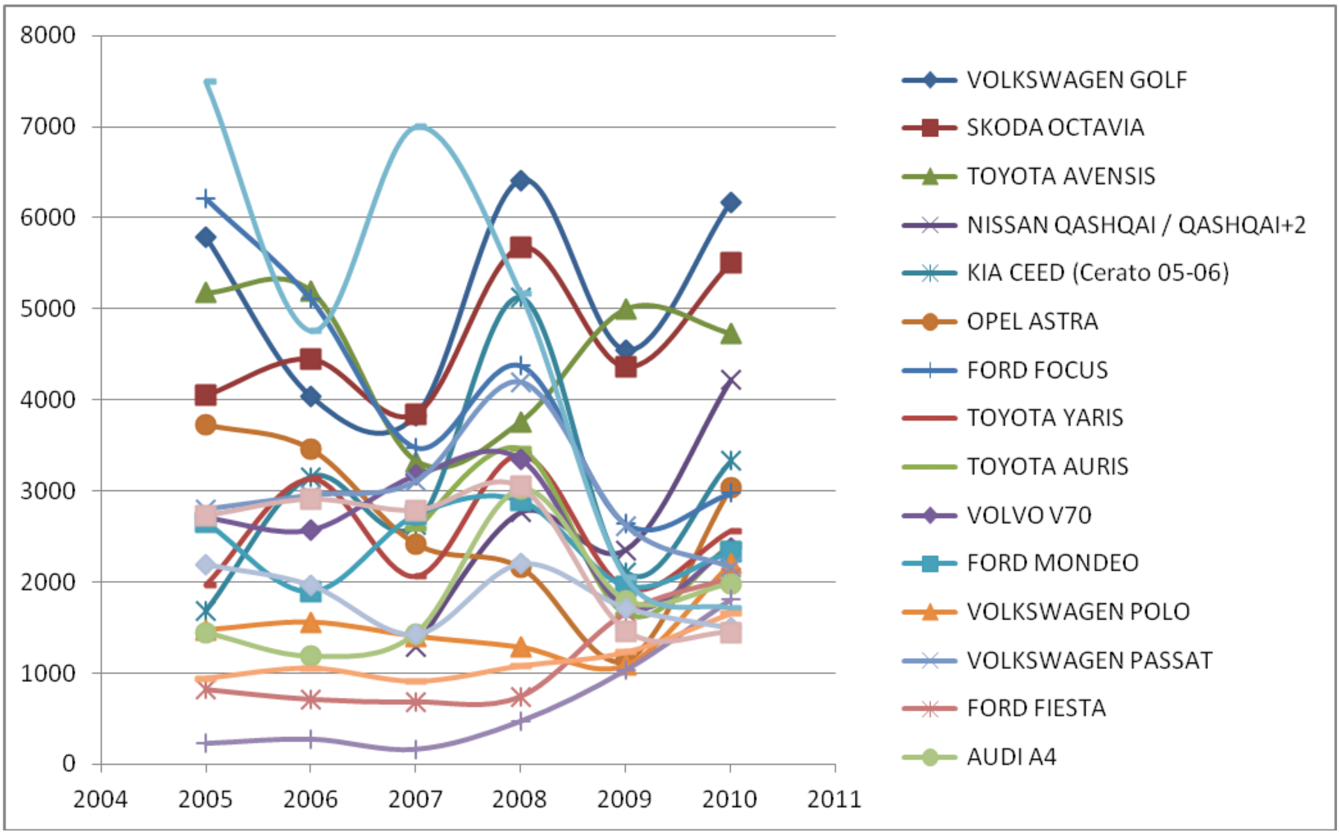

Figure 5. Annual sales of 20 best selling car models in 2010. These models represent app. half of the annual car sales in Finland. Data source Autoalan tiedotuskeskus (2011).

In practice the sales of EVs start by one or few models to enter to market. It may be expected, that if the manufacturer is willing to gain market, the launching will be made with a strong campaign so that the model might sell 500 to 1000 units during the first year. Naturally this requires the product itself, required services and pricing to fit to the car markets. As is seen in Figure 5, there is more than 10 brands in top 20 model selection, so it may be expected, that when EVs really enter the markets, 2 to 4 brands may offer an EV for the first year. And further on, within few years all the important brands have an EV in their model selection, as they use to have models for the different categories today.

In this work the sales development is set to start from 2000 EVs sold in first year (1,3 % market share) and the second year sales is 6000 (4 % market share). This is based on the idea, that in first year there is 2–4 models available and they double the sales for the next year. In addition to that, 2–4 new models enter the market next year. From then on, the sales growth decreases.

The effect of the shorter life time of EV's compared to the life time of combustion engine cars means that the annual sales compared to the EVs in service is not the same as with combustion engine cars. For this reason there is made an assumption, that the sales numbers are generated from the EV penetration, not vice versa. Though the start of EV penetration is based on the sales growth model described above, the penetration growth is calculated as if EV lifetime were same as combustion engine car life time. Then, after the life time of the first EVs become fulfilled, there will be extra sales compared to sales numbers of longer combustion engine car life time. And when the EV penetration reaches a stabile level, annual sales of EVs will have a larger share of sales than EV share of all vehicles in use.

The sales figures in Figure 6 are based on population growth estimate from Statistics in Finland and the car density development described in chapter 2.2. The equivalent EV sales means sales of EVs if the life time of EVs were 19 years as for combustion engine cars. The actual estimated EV sales is generated from equivalent EV sales taken into account the shorter EV life time.

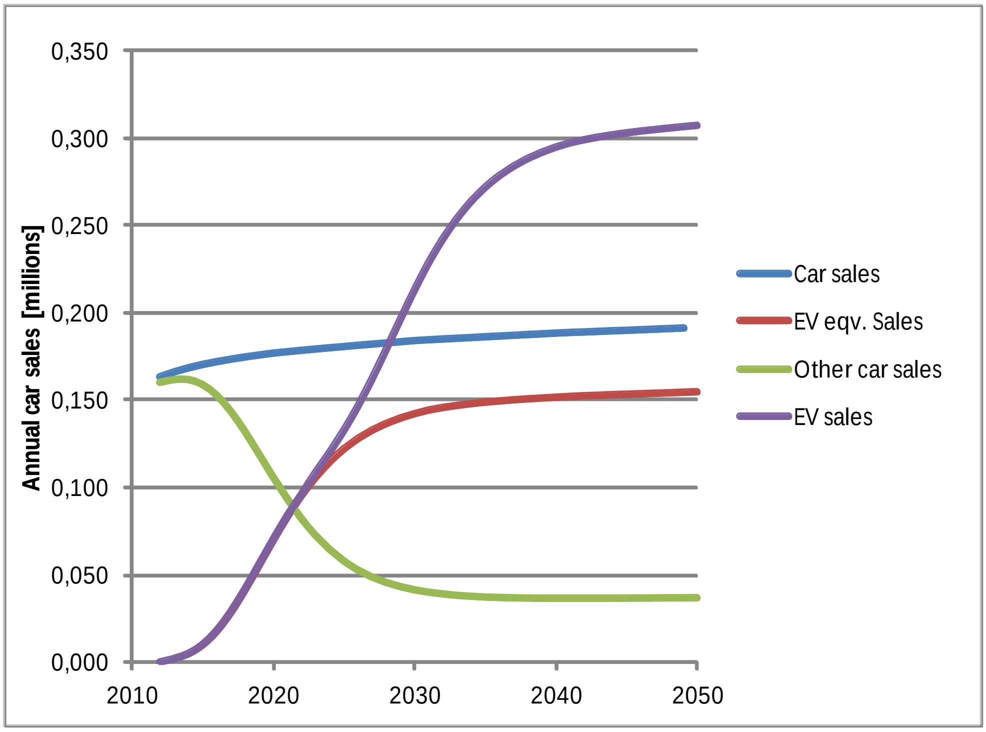

Figure 6. Estimated annual car and EV sales in millions of units. Car sales is sales without EVs entering to market. EV eqv. sales is EV sales if the life time of EVs were same as combustion engine car life time. EV sales is sales of shorter (10 years) life time EVs.

2.7. Heating and air conditioning

As discussed in the first phase of this work package (Alku & Kosonen 2011a), heating of the EVs must be taken into account when calculating the energy consumption and emissions of EVs. As the heating has been based on the waste heat of the combustion engine, there are no statistics from Finland about the energy used for car heating. Basically same applies to air conditioning that is operated mechanically with the combustion engine power. There is only an idea, that using air conditioning may increase the fuel consumption with f.ex. one litre per 100 kms.

Farrington and Rugh (2000) has studied the impact of air conditioning to fuel economy in USA where cooling is similar need as heating in Finland. The experience and the simulations show that fuel consumption may increase with 20 to 50 % because of the air conditioning being used 107–121 hour per year. The lower percentage is for mid size car having a weight of 1400 kg and average fuel consumption of 8,8 L/100 km.

In the work of Farrington and Rugh the vehicle skin heat transfer coefficient was 50 W/K representing an ordinary car manufacturing practice. The intake air flow for cooling mode was 167 g/s and for heating 111 g/s. With these values the maximum cooling power was 13 kW and heating power 6,1 kW. The work showed, that the share of air circulation is the dominant for required power. With 100 % recirculated air cooling power was 2,0 kW and heating 1,7 kW.

Hopkins and Türler (2011) studied the possibilities to improve the insulation of a car. Rebuilding a new Ford Taurus they gained 75–80 % improvement in heath transfer of a car shell. As the importance of low heat transfer is an important aspect with EVs, the heat transfer coefficients of future constructions may be better than the current ones. But at the same time, the air circulation must be optimised too. Because of the breathing load of the passengers, there will be a lower limit for recirculation. Farrington and Rugh stated that 8,5 g/s fresh air is required for a person in a car to maintain the contamination and humidity of the air inside a car. This is practically same as what is stated in European standard EN 14813-1.

Heating device is a must in Nordic conditions but air conditioning is an option. Still air conditioning has become a popular accessory in low priced cars too. Based on this, it is probable, that air conditioning will be a standard accessory in EVs, which may not be priced into the lowest car price category. It is also an option for heating as it reduces the battery load compared to direct electric heating.

The need for heating and air conditioning in vehicles is based on weather circumstances. The need to heat or cool a vehicle inside depends on the difference between the desired inside temperature and outside temperature. Annual need for heating the buildings is published from 16 locations in Finland as annual heating need rate (*lämmitystarveluku*) $S17_{heat}$ for 17°C inside temperature. The rate varies from 3896 in south (Jomala) to 6381 in north (Ivalo) (Ilmatieteen laitos 2011), see **Virhe. Viitteen lähdettä ei löytynyt.** In calculating the values the days with average temperature over 10°C in spring and 12°C in autumn are excluded, because heating of building usually is cut off and on based on these temperatures.

Table 1. Annual heating rate values in Finland. Values are based on weather statistics from years 1971 to 2000. Source Ilmatieteen laitos (2011).

Lämmitystarveluvut vertailukaudella 1971-2000

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	vuosi
Jomala	599	577	559	424	216	36	7	22	160	320	433	543	3896
Vantaa	691	647	593	402	165	18	4	27	185	364	502	631	4229
Helsinki-Kaisaniemi	657	619	574	404	169	12	2	15	144	331	468	594	3989
Pori	680	639	589	413	189	25	5	29	195	364	500	627	4255
Turku	667	629	582	399	170	19	4	23	170	352	488	612	4115
Tampere-Pirkkala	734	681	614	411	186	29	6	39	211	382	537	672	4502
Lahti Laune	737	686	615	419	172	25	6	36	215	394	533	674	4512
Lappeenranta	771	702	624	425	177	26	6	34	204	404	548	691	4612
Jyväskylä	789	727	650	464	217	43	13	63	251	427	576	725	4945
Vaasa	732	667	620	445	215	33	9	47	221	397	535	667	4588
Kuopio	820	748	657	468	213	34	8	43	216	415	579	742	4943
Joensuu	837	762	670	479	231	43	12	55	237	434	598	759	5117
Kajaani	867	783	695	502	260	59	21	82	266	460	630	795	5420
Oulu	829	749	674	484	263	49	11	62	243	442	606	758	5170
Sodankylä	964	840	759	570	358	113	55	150	330	545	742	911	6337
Ivalo	947	823	752	575	387	153	76	157	328	545	744	894	6381

To be precise, it should be known what is the deviation of driven kilometres and drive time in various parts in Finland. Then the temperature and sun shine statistics should be taken into account. To go forward in calculation, certain information about the car body construction should be known, as the heat conductance of the saloon, amount of fresh air taken in and the heat absorption of the body and it's paint colour. As this information is not available from the future construction practice of EV bodies, a simpler approach is used.

The energy required for heating a building or a vehicle is calculated as a product of heat loss power of the vehicle, time the vehicle is in use and heating need rate. Same applies to the need to cool the vehicle inside. In the form of a formula:

{1} $Q_{heat} = k_{shell} \times p_{air} \times S17_{heat} \times t_{day}$

where:

Q_{heat} =	annual energy required for heating
k_{shell} =	heat transfer factor of car body shell
p_{air} =	heating power of intake air flow
$S17_{heat}$ =	annual heating rate value for reference temperature of 17°C
t_{day} =	time the vehicle is in use during a day

For cooling the heat emission from a human body and heat absorption from the sunshine may be taken into account. The impact of the sunshine is excluded in this work because of the minor volume. Then the formula for cooling is:

{2} $Q_{cool} = k_{shell} \times p_{air} \times p_{human} \times n_{human} \times S17_{cool} \times t_{day}$

where:

Q_{cool} =	annual energy required for cooling
k_{shell} =	heat transfer factor of car body shell
p_{air} =	heating power of intake air flow
p_{human} =	heating power of a human body
n_{human} =	average number of humans in a car
$S17_{cool}$ =	annual heating rate value for reference temperature of 17°C
t_{day} =	time the vehicle is in use during a day

The heat transfer factor k_{shell} of car bodies is set to 50 W/K in this work. The thermal power p_{air} required for the circulated air is calculated from 0,01 kg/s air flow per person (based on EN 14813-1) and 1 kJ/kgK thermal energy capacity of the air. This ends to p_{air} value of 10 W/K heat transfer per person caused by air circulation. Average number of persons in a car n_{human} is 1,2. The heat load of a human body p_{human} is 118 W.

In the statistics the annual heating need rates vary quite strongly also between locations near each other (see Table 1). As an example, the rate for Kaisaniemi in Helsinki is 3989 and only about 15 kms to north in Vantaa the rate is 4229. **The 17°C rate $S17_{heat}$ for this work is set to 4100. For cooling a $S17_{cool}$ rate value of 60 is counted from the Helsinki temperature statistics.**

It is assumed, that the heating and also the cooling of the vehicle is started already before the use of the EV using the energy from the grid as the vehicle is connected to the power supply anyway at least in the mornings. This saves battery capacity and is both safety and comfort feature. **The heating and cooling time is set to be 15 minutes before the use of the vehicle. Annual time for this pre-heating or cooling is 90 hours a year.**

The usage time of the car is calculated from the LIPASTO statistic's share of driven kilometres. In LIPASTO the share of kilometres driven in city centre streets is 35 % of annual driven kilometres. Assuming that average speed in cities is 35 kms/h and outside city centres 80 kms/h, annual car use time is 326 hours. This value conforms to mobility survey statistics.

Based on all above, HVAC energy required for a P-EV used for 18 000 kms per year in Finland is 294 kWh. This is 8,2 % of the calculated annual energy used for moving the vehicle.

In case of RE-EV it is assumed that all the kilometres driven with oil are outside a city centre. During these kilometres the heating is taken from the heat loss of the range extender engine and this energy is not counted as required heating energy. In case of RE-EV the cooling is operated with electricity also when the range extender engine is in use. Therefore the cooling causes extra oil fuel consumption for the RE-EV. Because of this energy consumption is minor compared to total annual energy consumption of the car, this consumption is not calculated separately and is assumed to be included into the fuel consumption.

2.8. Electricity production development

Electricity usage of the traffic and electricity production was discussed in the first phase of this work package (Alku & Kosonen 2011a). Using intelligent technologies and combining renewable electricity production methods, it is theoretically possible to run electric traffic with practically zero climate gas emissions. On the other hand, there is always a question of how to allocate limited resources. Renewable existing and potential resources are limited not to be able to cover the whole electricity demand and there is no fair method to say, why just traffic would be the sector that may use the renewable production.

By means of pollution, environment does not ask who was the one that generated the negative impacts. Therefore it is fair to summarize the whole electricity production and count an average emission rate, which currently is in Finland app. 220 g CO_2 per kWh. Anyhow as traffic requires to increase electricity production, it is worth for to calculate the shifting in emissions caused by increasing demand from electric vehicles.

As a base of electricity production demand the known future is taken into account. One nuclear power plant in Olkiluoto is already under construction. It may be in production in 2013 when it adds 1600 MW power to electricity production power. This amount can be used to decrease current condensate power which is at the level of 2000 MW.

Finnish parliament has decided 1.7.2010 to let build new nuclear power capacity in Finland. Fourth power plant to Olkiluoto is expected to be in production in 2019 with a maximum power of 1800 MW. Other company, Fennovoima Ltd got also a permission to 1800 MW nuclear power plant. It is planned to be in production in 2020.

If all the current nuclear power plants are in service in 2020, nuclear power capacity is 7896 MW. The owner of the two first nuclear power plants in Finland, Fortum Ltd, expects that the first plants in Loviisa will be closed in 2029 reducing nuclear power capacity by 976 MW. Fortum also asked 2010 for a permission to build a new plant but did not succeed.

In this work it is estimated, that nuclear power will replace first the current condensate power capacity, app. 2000 MW. Also Finnish electricity industry counts that some condensate power plants will be closed before 2030 (Energiatelollisuus ry. 2009).

CHP capacity is bound to the need of district heating and process industry. The current electricity production capacity is app. 4750 MW and annual production is 29 TWh. In this work CHP capacity is assumed to grow following the population growth. This is different than the estimate of the Energiateollisuus in 2009, which is based on the age of the plants without an idea of how the heat is generated after the lifetime of the current CHP plants.

Water power and electricity import is assumed to be used as adjusting capacity. There are no realistic plans to increase water power capacity, so it is assumed to remain at the current level of 2200 MW and 13,5 TWh annual production.

The role of solar and wind power in Finland is open. The current share of these both together is 0,2 % of energy production. Current energy policy describes, that the share of renewable energy will be 38 % in 2020 and 60 % in 2050 (Valtioneuvosto 2009). The policy does not display any estimate of the share of technologies inside renewable production. It is only said in the policy, that there are some kind of plans for 5000 MW wind power capacity, which is remarkable compared to the estimated electricity demand in 2030.

Rest of the demand is filled with import, which is also used as adjusting capacity. Current main sources are Sweden (hydro) and Russia (nuclear).

According to Energiateollisuus ry (2009) the peak power demand in 2030 will be 18 000 MW. Annual peak power demand growth from 2015 to 2030 is 170 MW. Electricity consumption in 2030 is estimated to be 110 TWh and annual growth from 2015 to 2030 is 1,2 TWh. The estimate of Energiateollisuus includes 3 TWh electricity consumption in traffic in 2030, of which 2,4 TWh is used in EVs. The EV electricity consumption is based on Kronström's (2009) work.

The estimate of Energiateollisuus ry. seems to include an assumption, that electricity consumption per capita will have a slightly increasing growth when compared to the population growth estimate used in this work. When the EV energy consumption is removed from the estimate, all other electricity consumption per capita grows in the beginning of the era with 0,94 % per annum and in 2030 with 0,82 % per annum. In 2015 electricity consumption would be 16,8 kWh per citizen and in 2030 18,5 kWh. To extrapolate the trend of Energiateollisuus ry., electricity consumption per capita would be 21,1 kWh in 2050. The ratio between peak power and annual consumption is constant.

The electricity production scheme is summarized in Figure 7. The share "Other" includes condensate power, import and possible development of wind and solar power capacity. The demand in the figure does not include electricity required for the EV fleet. That demand will be filled with the production methods in "Other" part of the figure.

The electricity production technology specific CO_2-emissions are listed in Table 2. The values are based on VTT (2009) and Energiateollisuus ry. (2011) statistics from the latest 24 months. The emissions of renewable and nuclear power are life time emissions mostly generated from the building and demolishing of the plants.

Table 2. Specific CO_2-emissions for different electricity production technologies.

- Nuclear power 20 g/kWh
- CHP (latest 24 month in Finland) 220 g/kWh
- Wood power 32 g/kWh
- Water power 42,5 g/kWh
- Condensate coal power (latest 24 month in Finland) 790 g/kWh

The emission impact of EVs depends on development in CHP production and future solutions to fill the gap between demand and domestic production. Domestic condensate production has been at the level of 12,5 TWh/year during last two years. The current capacity of condensate power may fill the gap up to 2035, but specific emission value is against the emission development goals.

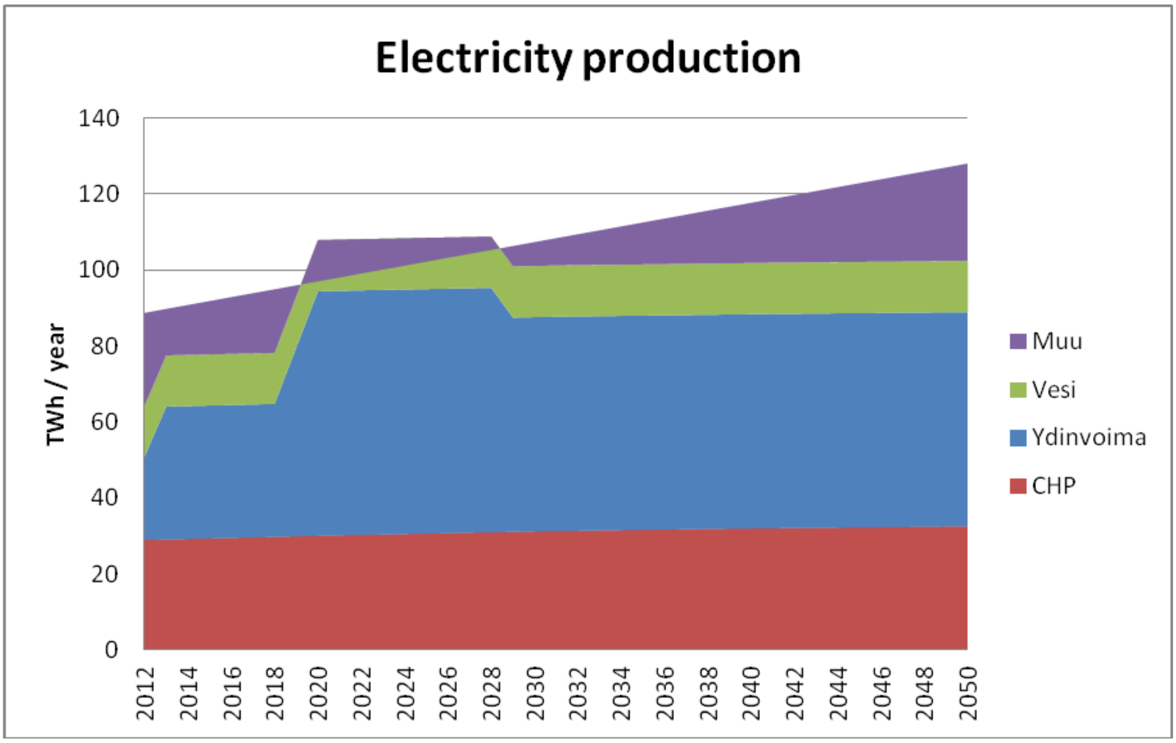

Figure 7. Electricity production by technology up to 2050 without the demand caused by EVs. Between 2020–2028 domestic production exceeds the demand.

2.9. Manufacturing impacts

The life cycle impacts of EVs include also the manufacturing and disposal of the EV and it's battery. Samaras & Meisterling (2008) has studied life cycle impacts of electric propulsion using Toyota Corolla as an example of a combustion engine car and Toyota Prius as hybrid example. The study included also plug in hybrids with up to 20 kWh battery capacity. The life time of a car was 240 000 kms. and average energy consumption in EV mode was 0.18 kWh/km.

Environmental load of production of the base car was considered equal to all car types. Amount of primary energy consumed was 0,4 MJ/km. Environmental load of battery varied according to battery capacity and was 0,14 MJ/km with 20 kWh capacity. Measured in primary energy, share of battery was 35 % of the base car manufacturing environmental load. When total life time energy of a plug in hybrid EV was 2,2 MJ/km, share of manufacturing the car and battery was 25 % of the life time energy consumed.

Samaras & Meisterling (2008) counted various scenarios, one important variable being the carbon intensity of electricity production. The low carbon scenario with 200 g/kWh electricity production carbon intensity corresponds best to Finnish circumstances. With this scenario life time green house gas emissions were 96 g/km measured in CO_2-equivalent. The manufacturing covered approximately one third of the life time emissions, electric kilometres another third and gasoline driven kilometres the last third (Figure 8).

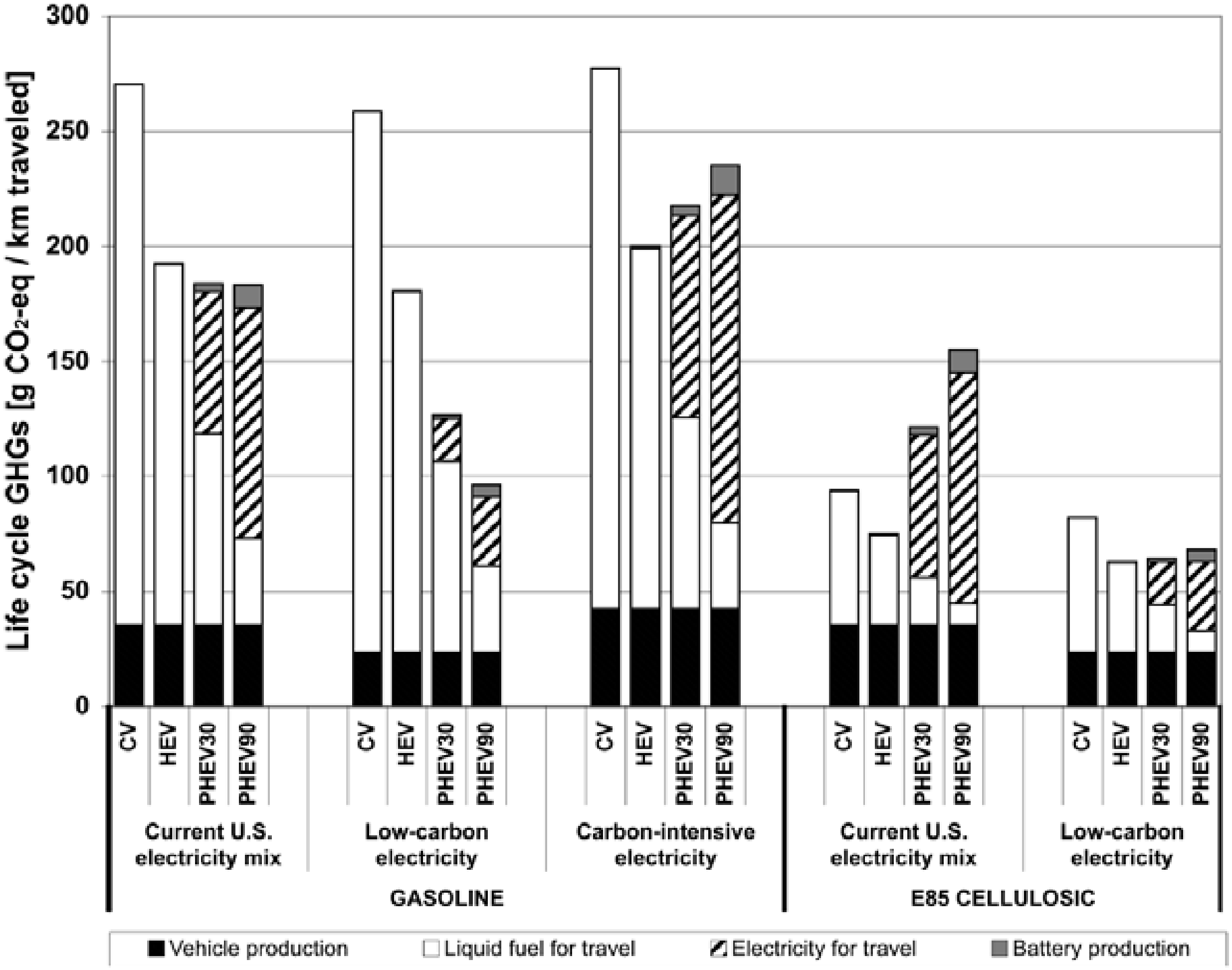

Figure 8. Life cycle GHG emissions sensitivity of CVs, HEVs, and PHEVs with 30 and 90 all-electric km ranges under different fuel and electricity carbon intensities. Life cycle carbon intensity of electricity assumed to be 670, 200, and 950 g CO_2-eq/kWh for U.S. average, low-carbon, and carbon-intensive scenarios, respectively. "E85" is a liquid fuel with 85% cellulosic ethanol (volume basis), and the remainder gasoline. Life cycle carbon intensity of gasoline and E85 are 86 and 21 g CO_2-eq/MJ, respectively. (Samaras & Meisterling (2008)

As in the work of Samaras & Meisterling (2008), an EV is considered as similar technology product as a combustion engine car. In this work the manufacturing environmental impact is considered to be dependent on the vehicle weight without the battery and the impact is considered to be constant per weight unit. Anyhow this assumption is limited to be valid only for a car like construction which is not possible to exist in less than 400 kgs tare weight**. In this work the energy use in car production is 70 MJ (19,4 kWh) per one kilogram of a car** (Samaras & Meisterling 2008). The CO_2 emission of manufacturing one car with 1500 kg mass is 3.3 tons when electricity production carbon intensity is 115 g/kWh.

The manufacturing impact of the battery is based on the Li-Ion technology. The manufacturing is based on the mining and diesel operated vehicles used in mining. 25 % of the energy used in battery manufacturing is diesel fuel. The general idea is, that it will be difficult to replace diesel engines in heavy vehicles until 2050. Therefore 25 % diesel share of the manufacturing impact of a battery is kept constant by time. **The energy consumption of the Li-Ion battery production is 1 700 MJ/kWh (472 kWh/kWh) of battery capacity (Samaras & Meisterling 2008), of which 25 % is generated from fossil diesel fuel.**

Cars are not produced in large scale in Finland and the manufacturing emissions are not counted to the green house gas emissions generated in Finland. By means of global emission load, each car imported and sold to Finland causes a global emission load based on the behaviour of a Finnish citizen. On the other hand, it is not sensible to adjust the green house gas emissions based on if cars are manufactured in Finland or in some other country. Therefore the emission load of car manufacturing is counted as a part of environmental impact of traffic in Finland.

Manufacturing impact is energy intensive, as car factories are run with electricity. Therefore the manufacturing impact is bound to the electricity production carbon intensity profile and it's development. There is variation in electricity production between countries. As it is difficult to estimate where cars and EVs used in Finland will be manufactured, the electricity production emission estimate for Finland is used in this work. This may be also argued with the international emission exchange.

2.10. External impacts

Traffic has direct and indirect environmental impacts. To share the impacts to direct and indirect is partially difficult. The impacts of manufacturing, use and scrapping or recycling (EOL = End of Life time) of the vehicles and impacts of building and using of traffic infrastructure cause direct impacts. Congestion and accidents are also direct impacts. But to manage these impacts may cause other impacts in the structures where and with which these impacts are managed. As an example, the increase in electricity consumption may cause a change to the electricity production industry because of the growth of electricity markets.

If the concept of a car remains similar to a combustion engine car, the external environmental impacts are considered to remain as they are currently. This is because of the change in propulsion technology has no connection to external impacts caused by traffic itself. As the share of EVs seems to grow slowly, there is no good reasons to estimate remarkable development in mobility behaviour and external impacts of the car traffic. The only change may happen if the amount of car traffic change for reasons that are independent of the propulsion technology. It is f.ex. shifting towards public transport in urban areas and reducing the need of human mobility by increasing delivery services.

In this work no further discussion about external impacts is made. The share of EVs during the coming 10 to 20 years will not be dominant and it is not expected that EVs might have remarkable effect to the traffic system. For the time period from 2030 to 2050 it is too uncertain to estimate the development. Instead the estimations should be made the opposite way by setting goals and expect that the society will find the required solutions. Those solutions may be based on the potential of electric propulsion technology and the mobility modes it can offer through new vehicle concepts.

2.11. Traffic safety

If vehicle concepts will develop towards light single person vehicles with lower speeds than current car traffic and this new traffic mode will be segregated from heavy car traffic, it is considered that the safety of traffic is increased. The increase is based on the better safety of this new traffic mode and the safety of heavy car traffic remain as it is today.

If the new light vehicles will operate as mixed with heavy cars, that will lead to decrease of the safety. This is because of the light structure and performance difference from heavy cars are safety risks. So to have the benefit of possible lighter vehicles the structure of the traffic network must be developed to avoid mixed traffic environments.

The increase of the safety with segregated light vehicle traffic is estimated to follow the safety factor of speed. To make the traffic safer means solutions that keep the speeds low. If light vehicles are used with high speeds as current cars, safety will decrease because of the less passive safety features of lighter vehicles.

Electric propulsion make traffic and vehicle management easier than with combustion engine technology. This may speed up the implementation of smart traffic management systems that control the driving of the vehicles the same way as automatic train control systems in rail traffic. These smart systems may avoid the mistakes of the driver and calculate proposed routes based on on-line information about the traffic situation. When the control system is optimized for traffic safety, it can monitor the actions that are known to be safety risks. This way a significant increase in traffic safety may be gained.

3. Impacts results

3.1. Scenarios

3.1.1. Base scenario

The base scenario is, that electricity demand growth will be covered with technologies that do not increase the specific emissions from what it is in domestic electricity production from 2020 after the two new nuclear power plants are in service. It is, the level will not exceed 80 g/kWh. In this scenario the specific emission of CHP-production remain 220 g/kWh.

- EV sales and penetration follows the base guideline described in chapter 2.6.
- Combustion engine fuel and fuel used in RE-EVs extender engine is counted to be fossil fuel.
- No special actions are taken for changing mobility behaviour.

3.1.2. EU target scenario

To fulfill EU targets (see chapter 2.2) there must be used other actions than just technology development in cars like electric vehicles. In the first report of this work package the following methods were mentioned:

- Reducing passenger car drive-kilometers
- Increasing public transport utilization rate
- Other technical solutions in vehicles, such as improving payload ratio
- Lowering the specific emissions of electricity production

In addition to above, this scenario also includes stronger shifting to EV sales as the base scenario and the share of L-EVs will be dominant.

This scenario includes following actions:

- Passenger car drive kilometers are reduced with shifting from supermarkets to local shops so that daily grocery shopping is possible without a car. This is organized in urban areas. Sparsely built areas cover only app. 17 % of the population in 2005 (Helminen & Ristimäki 2007), so this action is effective in covering majority of the population. It is assumed, that car driven kilometers for shopping is reduced 60 % in 10 years.
- Passenger car drive kilometers are reduced in urban areas by increasing the modal share of public transport. This requires increasing service level of public transport and transition from car based structure zones towards moderate service public transport zones. At moderate public transport zones car trips per work day will be reduced from 1.7 to 1.1 trips. This equals to mobility behavior shifting from Espoo and Vantaa like practices to Helsinki suburban like practices. (See page 9 in Alku & Kosonen 2011b).

- Shifting from combustion engine cars to EVs is faster and weighted to lighter vehicles with less energy consumption. Need and use of RE-EVs is reduced with increasing car share and rental business. F.ex. trip to summer cottage is possible with moderate cost renting or car share or rented car after flight, train or bus trip.

- Bio fuel with 75 % recycled share replaces fossil fuel in combustion engine cars until 2040 starting from 2015.

- The regular use of coal is finished within 20 years in electricity production.

3.1.3. Coercion scenario

The EU target scenario can fulfil the EU target to 2050, but to gain the target for 2020 requires stronger actions. The 2020 target is considered necessary because it is said that the critical 2°C global warming depends on green house gas emission reduction in short term.

The idea of this scenario is to fulfil the set emission targets for 2020 without any probability to volunteer development to come true. The simple base is to gradually limit the fossil fuel sales to the amount that fits to the EU greenhouse emission goals. As it is impossible to simply reduce car use, alternative solutions are set to be available. It is to boost EV penetration and production of bio fuels. Partly this will happen by demand as using smaller combustion engine cars, increasing use of public transport when available and growing interest for bio fuels.

The actions are:

- Fossil fuel import and sales is limited gradually from 2014 to fit the EU goals for 2020 and 2050. To treat car users equally, fossil fuel sales is controlled. Fossil fuel credits are addressed to combustion engine cars and RE-EVs with valid traffic insurance. Credits may be transferred to other cars to balance fuel availability between those who drive more or less kilometres. The sales of fossil fuels in 2020 equals annual combustion engine cars including RE-EV extender engine driven kilometres to fall from 54,6 million kms in 2012 to 34,0 million kms in 2020. Sales limiting continues to 2050 according to EU goal.

- EV sales is supported with car and fuel taxing policy that make use of EVs significantly attractive alternative to combustion engine car. The purpose is to boost EV sales and penetration growth to replace the reduced combustion engine car use with EV use faster than in base scenario.

- Bio fuel development, production and sales is supported with taxing and product development financing. Conversion of old gasoline and diesel engine cars to use bio based fuels is also supported. The idea is to boost the use of carbon neutral liquid or gas fuels also in old car fleet.

- Service quality and quantity of public transport is enhanced to make public transport better alternative to private car use as in EU target scenario.

- Centralisation of shopping and services that increase car use demand will be controlled and punished f.ex. with environmental protection tax which is bound to the impact to car use demand and with obligation to offer local services. The purpose of these actions is to guarantee the alternative of using services and shopping independently of car use. The reduction in car use for shopping is the same as in EU target scenario.

3.1.4. Bio fuel scenario

The fourth scenario is based on idea, that EV sales cannot be boosted and mobility behaviour changes will not succeed. Then the only way to reduce green house gas emissions to fulfil EU targets is to reduce emissions from other cars than EVs. This may be organized with other propulsion technologies or shifting aggressively to bio fuels for combustion engines.

Other propulsion technologies than electric propulsion and batteries seem not to enter to market even with speed of EVs. And other technologies have the same problem as EVs to gain penetration. In real world they are sharing the new technology car markets and then may reduce EV market development. So in practice, the share of combustion engine cars will be the same as in case available new propulsion technology is only EV. Therefore the most probable way is to develop bio fuel production and sales.

The actions in this scenario are:

- Fossil fuel import and sales is limited gradually from 2014 to fit the EU goals for 2020 and 2050. To treat car users equally, fossil fuel sales is controlled. Fossil fuel credits are addressed to combustion engine cars and RE-EVs with valid traffic insurance and credits may be transferred to other cars. The share of bio fuels in 2020 is 42 % and in 2050 85 %.

- EV sales and penetration follows the base guideline described in chapter 2.6.

- Bio fuel development, production and sales is supported with taxing and product development financing. Conversion of old gasoline and diesel engine cars to use bio based fuels is also supported. The idea is to boost the use of carbon neutral liquid or gas fuels also in old car fleet.

- No special actions are taken for changing mobility behaviour.

3.2. CO_2-emission from car use

The exhaust gas emissions from electric vehicles are the emissions generated from electricity production and local emissions from RE-EVs. Other local emissions may exist if the heating of the EV is operated with fossil fuels. As HVAC energy consumption in Finnish weather seems to be relatively low, 8.2 % of the driving energy consumption of EV (see chapter 2.7), it is preferred to operate HVAC with electricity and using pre-heating and cooling which do not load battery.

The base scenario impact to CO_2-emission is displayed in Figure 9. The impact of electricity production emissions is not remarkable. To gain zero emission in electricity production would shift the blue line to follow the green line which displays the fuel consumption of RE-EVs range extender engine and other cars.

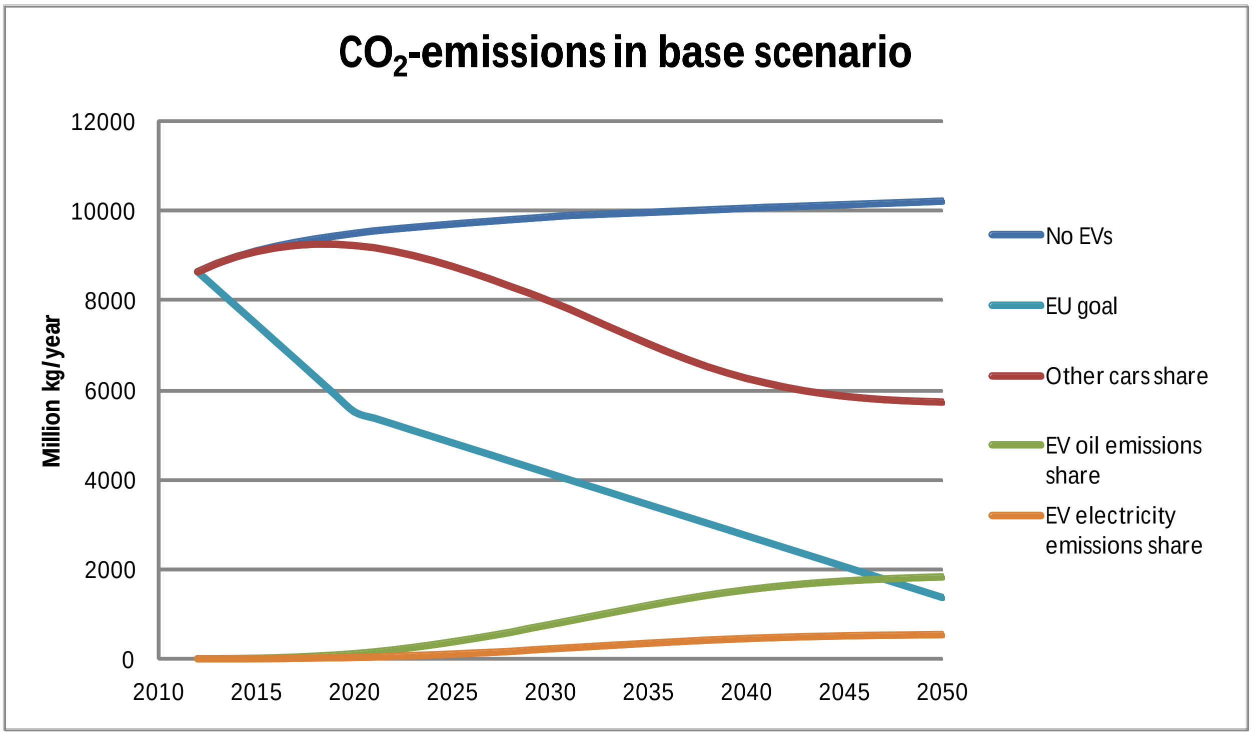

Figure 9. Base scenario CO_2-emission from car traffic including electricity operated HVAC in EVs and excluding the impact of EV manufacturing. The line "No EV" represents car traffic emissions without kilometers driven with EVs.

EU goals will never be fulfilled, if there will not happen green house gas emission reduction also in other car fleet than only EVs. CO_2-emissions with EU target scenario is displayed in Figure 10. The actions which have impact to mobility behavior, as re-organizing of grocery shopping and re-structuring built urban environment towards public transport based structure have immediate impact. If the positive mobility development finishes within 10 years, driven car kilometers turn to increase again. But then the penetration of EVs have a significant impact.

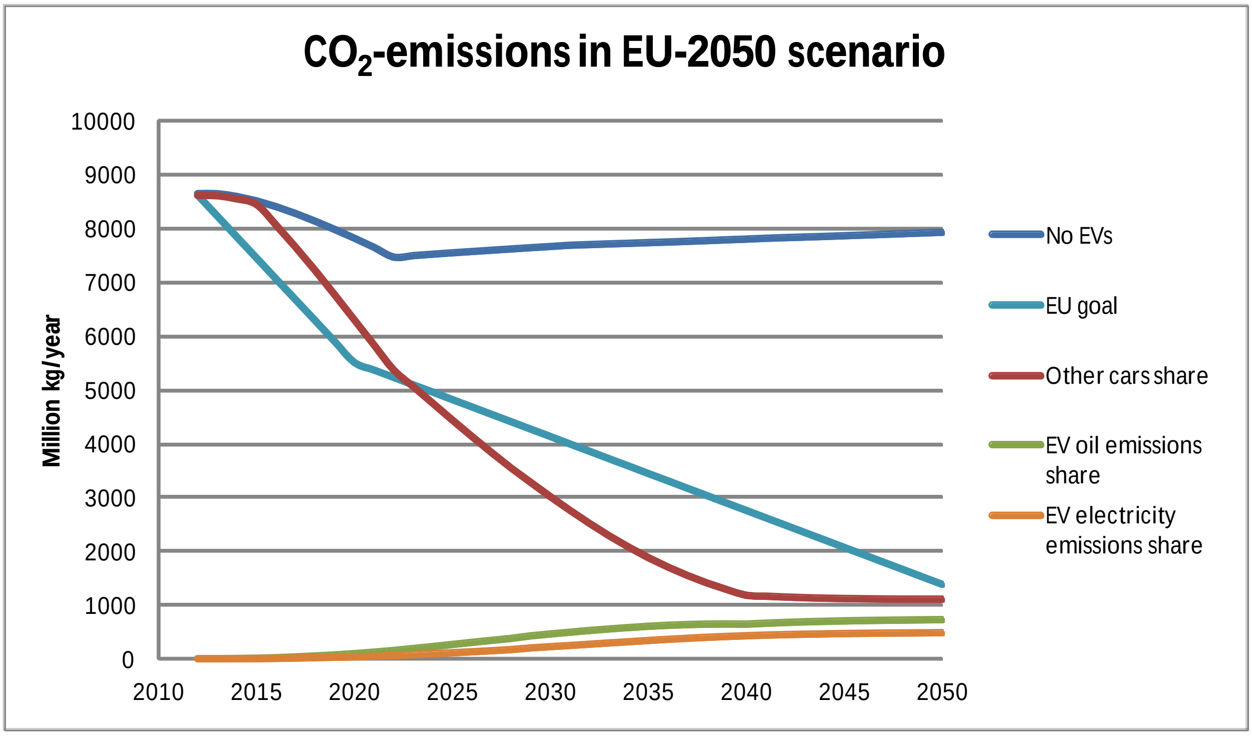

Figure 10. EU-scenario CO_2-emission from car traffic including electricity operated HVAC in EVs and excluding the impact of EV manufacturing. The line "No EV" represents car traffic emissions without kilometers driven with EVs, in other words the effect of mobility behavior changes.

With the EU-scenario of this work the EU green house emission target for 2050 can be achieved already 2040. The problem in fulfilling EU-targets is the short term target for 2020. It is very difficult to replace combustion engine cars fast enough. The 2020 EU-target equals no more than 1,90 million combustion engine cars using 10 % mixed bio fuel in 2020. To sell approximately one million EVs to replace combustion engine cars starting from 2014 equals all car sales to be EVs. This is not considered to be realistic.

The shape of emissions without EVs show the share of structural actions in reducing car use. The importance of structural actions is seen clearly: During the structural actions car use and therefore the base of car based emissions decreases clearly. As soon as these actions are finished, car use and emissions turn to increase.

The coercion scenario may solve the 2020 target when bio fuel share of combustion engine fuel sales is 21 % in 2020 and 40 % in 2050. EV sales is boosted so, that combustion engine car equivalent EV sales grows to 150 000 cars annual sales in 2021. Combustion engine car equivalent sales of EVs will then be over 90 % of car sales. Mobility behavior development is the same as in EU scenario. The resulting CO_2-emissions are displayed in Figure 11.

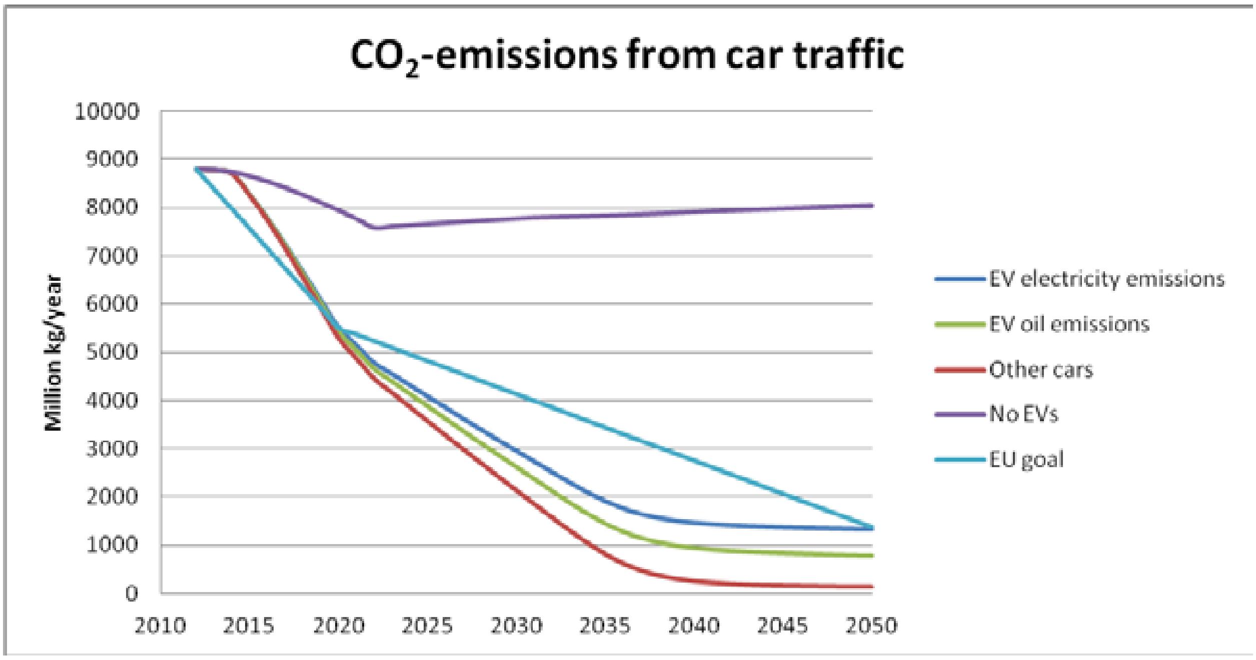

Figure 11. Coercion scenario CO_2-emissions from car traffic including electricity operated HVAC in EVs and excluding the impact of EV manufacturing. The line "No EV" represents car traffic emissions without kilometers driven with EVs, in other words the effect of mobility behavior changes.

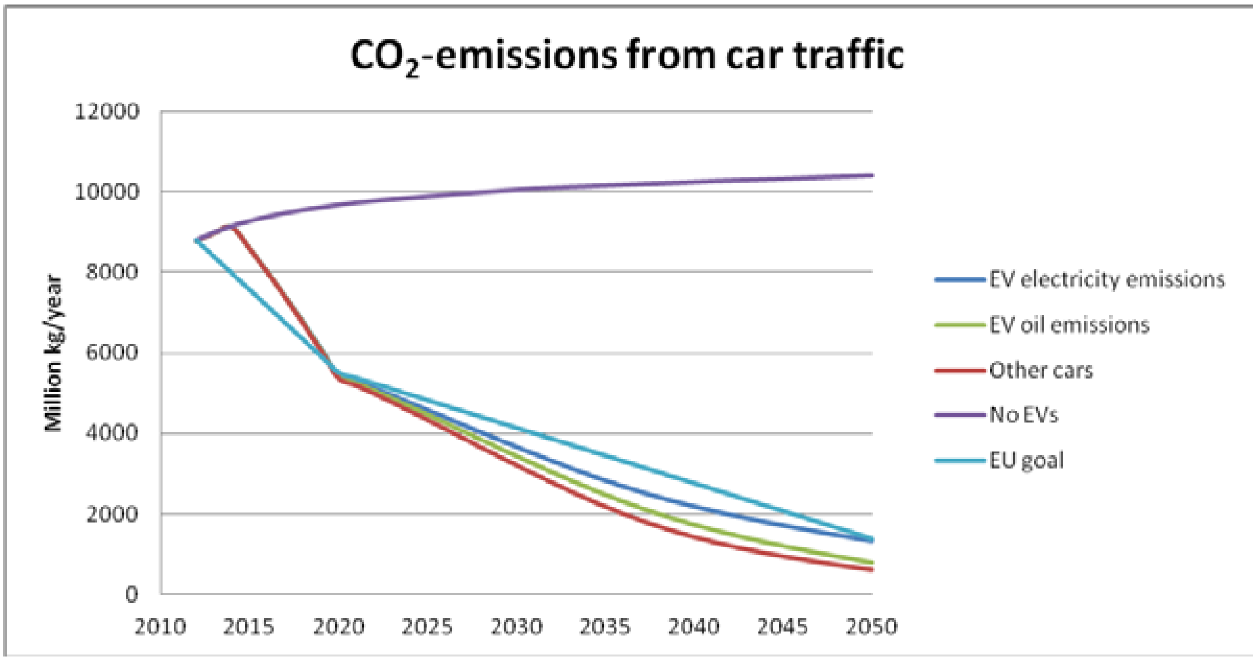

Figure 12. Bio fuel scenario CO_2-emissions from car traffic including electricity operated HVAC in EVs and excluding the impact of EV manufacturing. The line "No EV" represents car traffic emissions without kilometers driven with EVs.

The bio fuel scenario could be said to be the easiest and the most certain way to fulfil EU targets. When the share of bio fuel is controlled by limiting the supply of fossil fuels, there is no question if the sales of bio fuel is enough and are the car users willing to buy bio fuel. Anyhow there is no discussion here about if it is possible to produce sufficient amount of bio fuels and what is the cost of manufacturing and what is the sales price and impact to car use.

3.3. CO_2-emissions from car manufacturing

The effect of the car manufacturing is important in future of green house gas emissions. When counted with the current carbon intensity of Finnish electricity production, 115 g/kWh, the manufacturing of the new cars in 2012 generates 534 Mkg CO_2 emissions per year. The use of the cars generate 8800 Mkg CO_2 emissions. The share of manufacturing is 5,7 % of the total of green house gas emissions of the car traffic in Finland.

The manufacturing emissions of a single combustion engine car is calculated with 1500 kg mass. Emissions of one car are 3,3 tons CO_2-equivalent. In the base scenario the majority, 71 %, of EVs are RE-EVs, for which the mass without battery is set to 1400 kg and battery capacity is 20 kWh. The manufacturing emissions of the vehicle are 3,1 tons and the battery emissions are 1,4 tons making 4,6 tons CO_2 to manufacture one RE-EV.

The manufacturing of EVs is more emission intensive because of the energy intensity of the battery. When the life cycle of the EV is also shorter than the life cycle of a combustion engine car, the impact of the manufacturing is going to have more important role in the future. Figure 13 shows the comparison of the base scenario manufacturing impact to the situation, in which EVs are not manufactured and combustion engine cars are manufactured instead. The reduction of CO_2-emissions in electricity production reduces manufacturing emissions the way they do remain at the 2012 level until 2050.

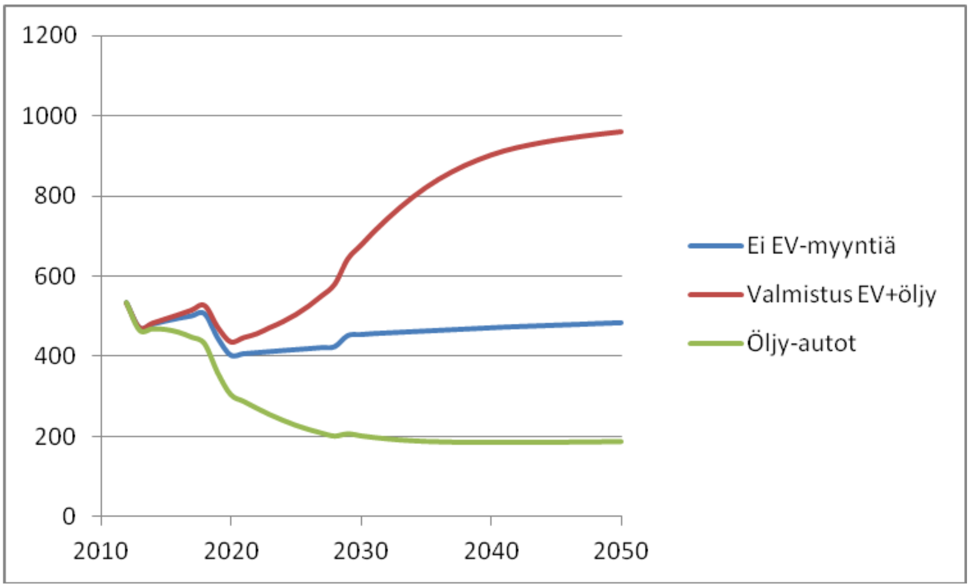

Figure 13. CO_2 emissions from manufacturing in the base scenario compared to the future development without EVs.

The total impact according to the base scenario of the use and manufacturing of the cars is shown in Figure 14Figure 15. The emissions from the use start to decrease after 2020, but the increasing sales of EVs increase manufacturing emissions. The increase of manufacturing emissions accelerates because of the short life time of the EVs.

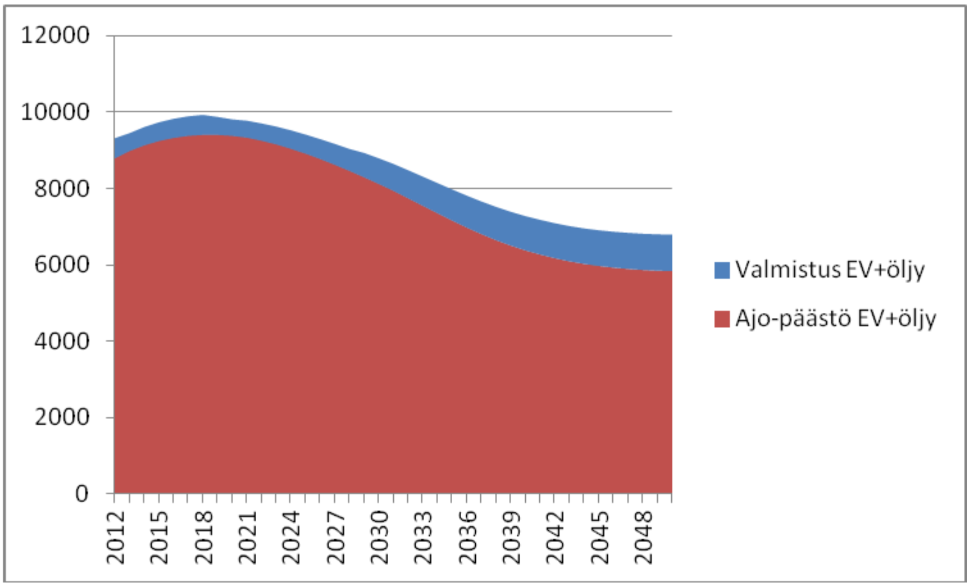

Figure 14. Total emissions in base scenario.

None of the scenarios results to decrease manufacturing emissions according to EU goals. The best combined emissions result is in bio fuel scenario. The emission level develops nearly according to EU target to 2020, but then manufacturing emissions increase because of the short life time of EVs and batteries.

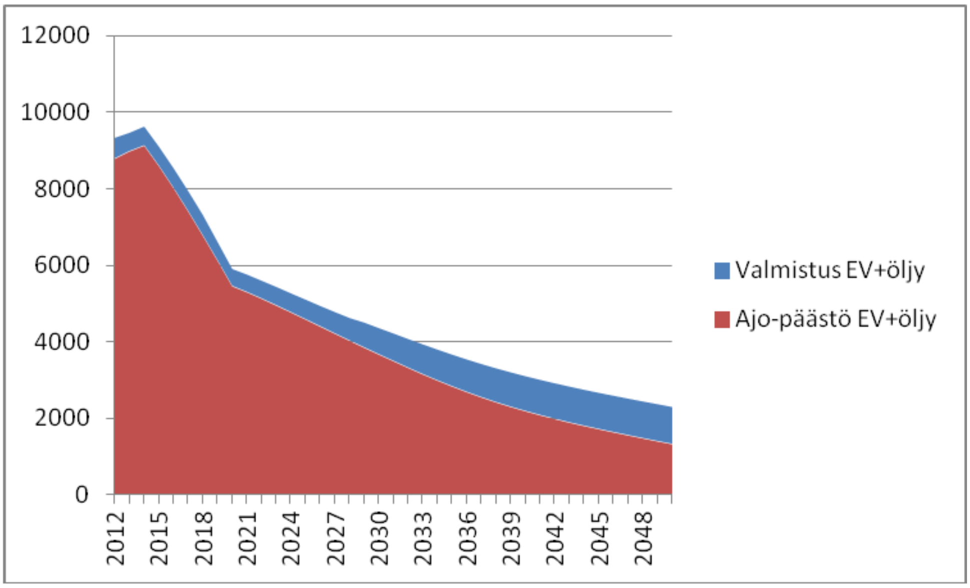

Figure 15. Total emissions in bio fuel scenario.

The cause for the development in Figure 15 is shorter EV life time than combustion engine life time. The share of manufacturing emissions is displayed in Figure 16. The large share of manufacturing vehicles may be decreased extending the vehicle life cycle. But even though the life cycle of the vehicle were 19 years as with combustion engine cars, the emissions from manufacturing batteries remain significant.

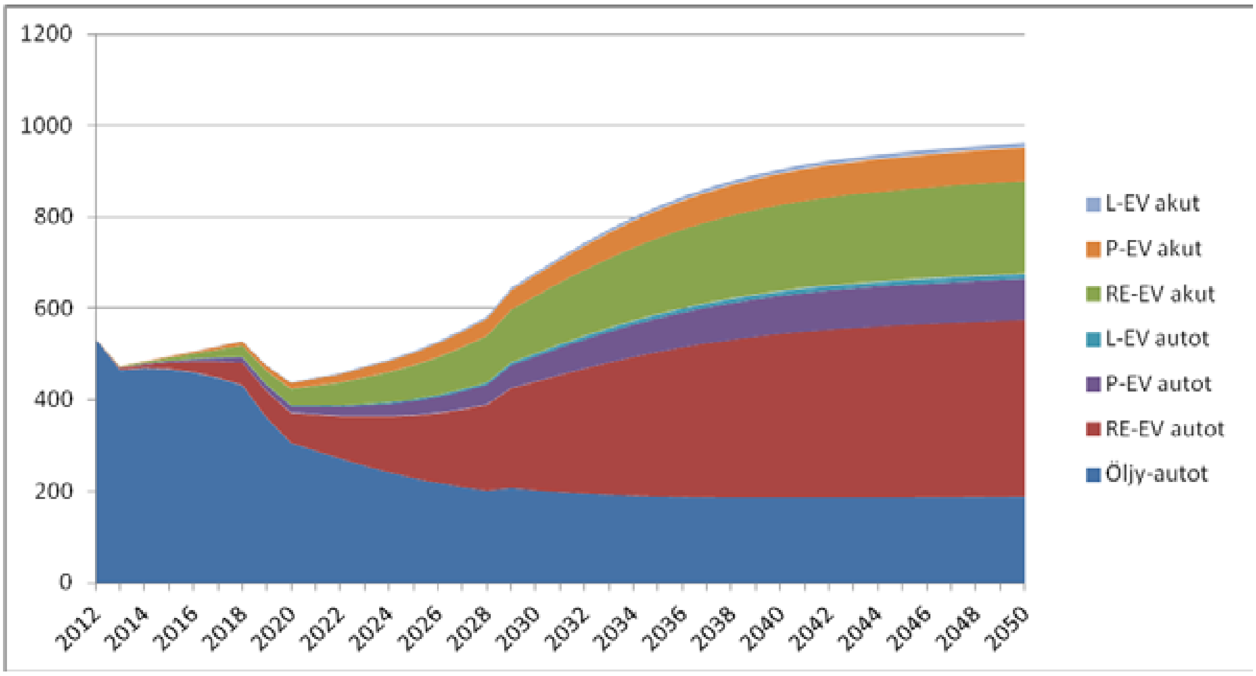

Figure 16. Share of manufacturing emissions in bio fuel scenario.

When battery life time is limited by means of technology, to reduce battery manufacturing emissions require reducing necessary battery capacity. That is possible with following actions:

- To reduce vehicle mass and that way energy consumption.
- To reduce necessary operating range by increasing charging network density.

Another approach is to reduce number of vehicles. That is possible during development of the urban structure, better public transport service and developed car share and rental markets. Based on experience from urban areas in Finland, car ownership may be reduced to app. 400 vehicles per 1000 citizens in urban areas.

As manufacturing emissions are mostly dependent on electricity production, the development in carbon intensity of electricity production has strong impact. In practice that development is out of Finland's national control.

4. Discussion

4.1. Limitations

This work has focused the green house gas emissions. Other impacts like indirect impact of car traffic and use of raw materials are not discussed. This is because especially in short term, meaning 10 to 15 years, there is not expected to happen any major change in mobility behaviour. Car usage will remain dominant mobility mode because the urban structure cannot change within few years.

The expected mobility changes in EU-2050 scenario and coercion scenario of this work are small compared to the mobility development from 1950's when the urban structure has switched to car based mobility. Those changes in the mentioned scenarios do not require changes in urban structure, only in mobility behaviour. Traffic infrastructure is capable to handle increasing public and delivery transport.

For the mentioned scenarios to come true there are actions and financing required for increasing public and delivery transport. That discussion is not included in this work. Also the environmental impact of public and delivery transport increase is not discussed. Based on current share of traffic emissions, the impact can be expected to be smaller than the overall uncertainty of the scenarios.

The life time of cars is long and resources to renew car fleet is limited. Therefore the urban structure must remain suitable to current mobility behaviour and EVs must adapt to the existing mobility structure during the nearest future. The signs from car industry also show, that the concept of a car seem not to change fast. Therefore indirect impacts and raw material usage remain as they are while the propulsion technology changes.

By means of climate change the most important focus is the development before year 2020. This is because the important matter is to stop the growth of emissions and limit the emissions for not to reach the critical level that may cause the global warming to exceed 2 degrees centigrade. It is also easiest to estimate to short term, as the uncertainty grows for longer terms. For all these reasons the main focus of the work is in the beginning of the time span.

The above mentioned mean, that the full potential of the electric propulsion technology is not used in this work. The light electric vehicle used in the scenarios is heavy compared to personal electric vehicles. And the smaller and lighter the EV base is, the larger can the EV share of vehicles be. This is because the limited battery production capacity can produce batteries for more vehicles when capacity in one vehicle is small. This is important aspect, as the dominant energy consumption and emission source is the other vehicle fleet than EVs.

4.2. Further Research

This work has indicated the importance of the short term development and the difficulty to increase EV penetration. To achieve short term development in traffic emissions, it is important to find out actions to speed up both EV supply and demand.

For longer term the full potential of EV technology should be investigated, but that requires also some decisions of the future policy of urban development and energy production. It is worth for to note, that solar and wind power policies may and should be combined to EV policy, as both can benefit of each other. Distributed energy production is discussed in energy policy papers (Valtioneuvosto 2009, VTT 2009), but the role of EVs and their batteries is still an open question.

Urban structure and urban development is one of the important topics in future discussion. That discussion has been based on traditional traffic solutions, in which a combustion engine car is the default mobility mode. Some thoughts of future urban structure are based on the need to reduce the negative impacts of combustion engine cars and heavy traffic infrastructure required for both cars and high capacity heavy rail solutions. EV technology and especially the potential of light electric vehicles may offer solutions that fit better to urban structure needs than what the traditional traffic solutions may offer. These topics are discussed in the last report of this SIMBe work package.

5. Conclusion

The aim of this work was to find out the environmental impact effect of electric vehicles. The time span was to 2050 and the target reference was the climate policy of European union.

The environmental impact of electric vehicle is usually considered as the difference of energy consumption and emissions when comparing a single EV to a single combustion engine car. It is known that the electricity production has some emissions, but they are thought to be smaller than those of an engine using fossil fuel. The main weakness of this approach is, that it does not take into account that a car fleet cannot be turned to EVs immediately.

The main result of this work is, that it is very difficult and practically impossible to gain remarkable car traffic short term emission reduction with EVs entering to market as a part of car production and supply. But in long term EVs are very effective in reducing traffic emissions. EVs have even larger potential than other propulsion technologies that require complicated and heavy mechanical structures like those in combustion engine cars. EV technology is suitable for light and personal vehicles which may offer more freedom to urban structure than current car concept.

Though EVs may not help to reduce car traffic emissions in short term, especially to the target year 2020, shifting towards electric mobility is worth for to start immediately. EVs may not gain market share, if the traffic system does not adapt and support the use of EVs. If the popularity of EVs remain weak, the penetration grows slowly and not even the long term benefits will come true.

For short term emission reduction it is necessary to use parallel actions with EVs entering to markets. The scenarios of this work indicate that during the next 10 years both improving public transport and reducing the need to use a car together with shifting towards electric mobility can start the positive development towards permanent reduction in car traffic emissions.

To shift from fossil oil based traffic fuels towards renewable fuel technology is the fastest way to reduce car traffic emissions. Anyhow bio fuel must be seen as a temporary solution for the short term aims and as a choice of the future energy alternatives in long terms. Unlike EV technology, bio fuel technology has major uncertainties what comes to production technology and capacity. Not only the problem, that bio fuels may compete with food production. Bio fuel may remain necessary for heavy vehicles, but for cars it is an energy choice that requires to continue with the combustion engine technology and its limitations in vehicle design.

EVs are for the most the long term solution, which is a drawback by means of fast emission reduction, but it has also some advantages. The early phase of EV penetration gives time to learn and practice with the technology choices and infrastructure implementation. To speed up the process requires public support, investments and taxing policy. In early phase all these do not load public economy and work organisations over their performance. That is a good reason to start as soon as possible and take the work seriously.

Summary of the statistics used

Battery capacity/weight –relation (Li-Ion) 0.202 kWh / 1 kg (http://www.batteryuniversity.com/parttwo-55.htm)
Battery capacity/weight –relation (Li-Ion) 1 kWh / 10 kg (Haakana 2008)
Battery capacity/volume –relation (Li-Ion) 0.514 kWh / 1 L (http://www.batteryuniversity.com/parttwo-55.htm)
Battery service life (lithium phosphate) 10 years (Battery manufacturer's specification)
Battery charge/discharge amount (lithium phosphate) 3000 (Battery manufacturer's specification)
Battery specific price for consumers 5.000-10.000 € / 10 kWh (European Batteries Oy)
Specific capacity of a solar panel, considering the efficiency coefficient of inverter and regulator, 100 W/m^2 (Savonia 2010)
The average capacity corresponding to the yearly yield of a solar panel in central Finland 15 W/m^2 (Savonia 2010)
Length of a commute driven with a passenger car 15 km (average in the Helsinki area)
Average life cycle of a passenger car in Finland 19 years (HLT 2006)
Average life cycle of an EV 10 years (see chapter 2.5)
The average usage of a passenger car in Finland 18.000 km/year (HLT 2006)
Average daily usage of a passenger car at 80 % probability at most 40 km (passenger car usage distribution in Henkilöliikennetutkimus (HLT 2006 6_31_tapa.xls))
Tax percentage in passenger car consumer price, about 40 %
Market price for coal in a port in Finland, price per thermal value, 8 €/MWh
Tax percentage in traffic fuel consumer price, about 60 %
(http://fi.wikipedia.org/wiki/Polttoainevero 8.4.2010 17:18)
Market price for traffic fuel, price per thermal value, 0,16 €/kWh
Density of wood chips 300 kg/m^3
Industry market price for wood, price per thermal value, 10–25 €/MWh
Density of wood logs when stacked 500 kg/m^3
Finnish passenger car stock 2.9 million cars in 2010 (Tilastokeskus 2011)
Car density in Finland 535 cars / 1000 inhabitants (Tilastokeskus 2011)
Maximum car density 600 cars / 1000 inhabitants (see chapter 2.2)
The yearly energy consumption of an electric car stock in Finland 9,2 TWh (Kronström 2009)
Practical battery capacity of an electric car 30 kWh (150 km range)
Nominal drive energy consumption of an electric car (tank-to-wheel) 0.2 kWh/km (Kronström 2009)
Consumer price of electricity 0.13 €/kWh
(http://www.sahkonhinta.fi/summariesandgraphs 8.4.2010 17:12)
Specific emission of electricity production in Finland 260 g/kWh (Energiateollisuus 2010)
Specific emission of combustion engine car in Finland 179 g/km (LIPASTO 2011)
The average effect corresponding to a wind power plant's yearly production, as share of nominal power 25 % (Holttinen ym. 1996, pp. 38–39)
The planned total wind power to be constructed in Finland 2000 MW (Matilainen 2008)

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