Electric cars
The climate impact of electric cars, focusing on carbon dioxide equivalent emissions

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Abstract

**Electric cars - The climate impact of electric cars, focusing on carbon dioxide equivalent emissions**

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This bachelor thesis examines and models the emissions of carbon dioxide equivalents of the composition of automobiles in Sweden 2012. The report will be based on three scenarios of electricity valuation principles, which are a snapshot perspective, a retrospective perspective and a future perspective. The snapshot perspective includes high and low values for electricity on the margin, the retrospective perspective includes Nordic and European electricity mix and the future perspective includes electricity on the margin for modest and high climate goals at 2030. The study is applied to an upcoming climate smart district, Brunnshög in Lund, and the goal is to determine the amount of emissions of carbon dioxide equivalents for the mentioned alternatives.

The environmental effects depend largely on the fuel consumption for the compared types of cars and what electricity valuation principle that is used. The car fleet of 2012 generated 10 300 tonnes of carbon dioxide emissions. The future car fleet generated 400 tonnes of emissions for Nordic electricity mix, 3 200 tonnes for European electricity mix, 3 100 tonnes for electricity on the margin with low values, 5 800 tonnes for electricity on the margin with high values, 1 200 tonnes for electricity on the margin at 2030 for high climate goals and 4 600 tonnes for electricity on the margin at 2030 for modest climate goals.

The emissions of carbon dioxide equivalents are at least halved in Brunnshög if 100 % electric cars are used instead of the composition of petrol, diesel and ethanol cars that are primarily used in Sweden 2012. Hence, the result shows that the electric car is very beneficial from an environmental and health perspective, compared to the composition of cars in Sweden 2012. However, how beneficial the electric car is, largely depends on the fuel consumption for both the electric car and the alternative compared with. Although to be able to increase the use of electric cars there are many challenges that need to be dealt with. In order to increase the use of electric cars, it will require further work in the development of batteries, expansion of charging points and other incentives, such as legislation and investments. It will also require a significant technology development to increase the range of the electric car. A natural step in the transition phase could be plug-in hybrids. It is also important to continue to implement climate smart districts, such as Brunnshög in Lund.
Preface

This project has been performed within the course, Independent Project in Sociotechnical Systems Engineering - Energy Systems at Uppsala University, 2012. The project was done on behalf of WSP Sweden, with contact person Stefan Ericsson, energy consultant at WSP Sweden. We would like to express our sincere gratitude and appreciation to Stefan for his dedication and support in the project. We wish to thank Agneta Persson, business developer on WSP Sweden and Erik Bellander, head of department at WSP Sweden, Electric Power. We would like to thank Joakim Munkhammar, Ph.D. student at department of engineering science at Uppsala University, who has supervised us through the project. We are grateful to Allan Larsson Vice Chairman and project Manager for Elbil2020, Björn Hugosson, unit manager at transport policy WSP Sweden and other employees at WSP Sweden, that have shown interest in our project.
Terms

Electric car
A car powered entirely by electricity. An electric car is provided with one or more electric motors and a secondary battery that can be charged.

Electric charging point
A charging point where electric cars can charge.

Carbon dioxide equivalent
The amount of a greenhouse gas, in terms of the amount of carbon dioxide, which has the same impact on the greenhouse effect. A measure that makes it easier to compare different greenhouse gases since they have different ability to absorb and reflect heat radiation.

Nordic electricity mix
The electricity production that is performed in a specific geographical area is henceforth called electricity mix. When Nordic electricity mix is used, the limited geographical area that includes the Scandinavian countries is intended and it is the average electricity production that is taken into consideration.

European electricity mix
The European electricity mix is defined as the average electricity production that is performed inside the geographical area defined as Europe.

Electricity on the margin
Electricity on the margin is composed by the production techniques that are used to cover a rapid change in the demand for electricity, that is the electricity production that are taken in use if the demand increases and that is taken out of service if the demand decreases. Those production techniques are often the most expensive and environmentally unfriendly.

Primary energy
Primary energy is the energy that is stored in natural resources. The energy is in its primary form and has not been transformed, as for example sunlight or crude oil. When electricity is produced there are always losses such as friction or heat losses. The amount of primary energy is therefore higher than the amount of energy that is reclaimed.

Energy density
Amount of energy stored per unit mass.

Emissions Trading
Emissions Trading is a market-based management control measure that handles pollutants by economic incentives for achieve reducing emissions of pollutants.
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1. Introduction

The electric car has been around for more than a century, yet there are only a few hundred electric cars on the Swedish market (Laddaelbilen, 2012). Since 1970, the passenger transportation has increased by 70 percent, where a high percentage of the current fleet vehicle uses fossil fuels (Trafikverket, 2012). The total emissions of greenhouse gases have also increased by 70 percent over the same period of time, where the fastest growth rate occurred between the years 2000 and 2008 (Naturvårdsverket, 2012a). The total number of carbon dioxide emissions from a Swedish person is 5.6 tonnes (Naturvårdsverket 2011d), where about 19 percent is generated by the road traffic (Trafikverket, 2012a).

Discussions on sustainable development have increased in connection with the development of economic, social and environmental measures to ensure a constantly improving quality of life for current and future generations (Regeringen, 2011a). Renewable transport solutions are required to achieve a sustainable society and to reduce carbon dioxide emissions. An increasing number of climate friendly districts are built where the electric car might be a component to reduce the climate impact. However, there may be uncertainty on the advantages of the electric car since the usage of electric cars will lead to an increasing use of electricity. Electricity can be produced in different ways and thus affect the climate in different ways. The introduction of electric cars will reduce the oil dependency but will require multiple incentives for a market development. (Larsson, Ö 2010)

This bachelor thesis examines the climate impact of electric cars, focusing on carbon dioxide equivalents emissions and is commissioned by WSP Sweden with Stefan Ericsson and Agneta Persson as representatives.

1.1 Aim

The aim of this study is to develop a model that examines the climate impact from the use of electric cars in comparison to the use of the Swedish present composition of automobiles. The model is general, but is applied on a case study, the city district Brunns Höög in Lund. The model calculates the emissions of carbon dioxide equivalents of the present composition of automobiles compared to the corresponding number of electric cars. The system boundary includes all journeys to and from Brunns Höög and the journeys inside the city district. The report treats three scenarios of electricity valuation principles: a snapshot perspective, a retrospective perspective and a future perspective. The snapshot perspective includes high and low values for electricity on the margin, the retrospective perspective includes Nordic and European electricity mix and the future perspective includes electricity on the margin for modest and high climate goals at 2030. In this report modest climate goals are intended to be 20 EUR/tonnes of CO₂ and high climate goals are intended to be 40-50 EUR/tonnes of CO₂, according to the Emissions Trading system. The report also treats electric cars in general and examines the obstacles of establishing electric cars and how to increase the usage of electric cars.
1.2 Research Questions

*How many tonnes of emissions of carbon dioxide equivalents will electric cars, inside the system boundary of Brunnshög, annually generate in comparison to the present composition of automobiles, regarding three different scenarios of electricity valuation principles?*

*What obstacles prevent a successful introduction of electric cars?*

1.3 Limitations

This report covers only the emissions from cars and not public transport or other electric vehicles, such as mopeds. In the report, there is no room to calculate how the different scenarios affect the environment besides emissions of carbon dioxide equivalents, although a discussion about other environmental effects will be considered. The model is only valid for Sweden and is applied on a sustainable district in Lund, Brunnshög, which induces the system boundary for the report. If an analysis of the amount of carbon dioxide equivalents generated by the transport sector is to be done for Brunnshög, this study has to be supplemented with the amount of emissions generated by public transport. The limitations concerning the model are presented in section 3, Methodology.
2. Background

2.1 Electric Cars in 2012

At the end of 2011 there were 336 electric cars registered in Sweden, which represents approximately 0.000083 percent of the total number of cars. In April 30th, 2012 there were 430 electric cars registered in Sweden, which equals a growth rate of 27.98 percent in only four months. (Appendix A, Table 9) Using electricity as fuel is not a new invention; it has been used for over a century. Electric cars have not had the same success as gasoline or diesel cars, but the increasing awareness and concern for the environment and exhaust emissions has increased the interest in electric cars. (Larminie and Lowry, 2003)

2.2 Advantages of Electric Cars

Electric cars on the Swedish market are few (Appendix A, Table 6) and many obstacle needs to be overcome. However, electric cars have many advantages against other cars with different fuels, such as:

- No emissions when used
- Reduced noise
- Energy efficiency
- Low operating costs

The growing concern for the environment and the fact that the transport sector accounts for about 30 percent of the total carbon dioxide emissions in Sweden, makes electric cars very beneficial (Trafikverket, 2012b). Electric cars provide no exhaust emissions when driving, which leads to positive health aspects when no unhealthy particles are released. Air pollution is one of the biggest environmental problems, which is why European Union, EU, has established guidelines and requirements for reduced emissions. (Naturvårdsverket, 2011a) The use of electricity in the transport sector would reduce the dependency on imported oil. Electricity is generated from many sources, such as wind power, nuclear power and hydroelectric power, which mean that the transport sector does not depend on one source. (Vattenfall, 2012) An increasing problem is noise from the transport sector and according to many research reports; this leads to negative health conditions such as heightened blood pressure and increased risk of heart disease. (Miljöforskning, 2009) The use of electric cars will however reduce the noise compared to the use of petrol cars. (Naturvårdsverket, 2011b) To reduce the consumption of electricity it is necessary to use the electricity more efficient. Electricity is more energy efficient than fossil fuels; see Section 5, Results, for further information.

The fuel cost for electric cars are low compared to petrol cars, which can be demonstrated with the following example; an approximate value of a fixed price for electricity is 1.5 SEK/kWh, including taxes and net costs (Energirådgivningen, 2012) and the average fuel consumption of an electric car is 1.58 kWh/10 km (Appendix A,
Table 6). The total price per 10 kilometres is calculated to be 2.37 SEK/10 km. The following values are specific to Lund where a mean value of fuel consumption for petrol cars is 0.83 litre/10 km (Appendix A, Table 4) and the gasoline price is 15.08 kr/litre. (Bensinpriser, 2012) The fuel cost per 10 kilometres for a petrol car is calculated to be 12.52 SEK/10 km. The prices vary for both petrol cars and electric cars, depending on locations, car model, driving habits and taxes. The example illustrates that the fuel cost is much lower for electric cars compared to petrol cars.

In the future, electric cars are likely to smooth out peaks in the grid, and thus be a part of the smart grid concept. How the electricity consumption varies in Sweden a winter and a summer day can be seen in Figure 1 and 2. The numbers that were used in both figures can be seen in Appendix A, Table 8. To smooth out the peaks the electric car can recharge when there is a decline on the electric grid and discharge when there is a peak. (Spane, 2010)

![Electricity consumption in Sweden Jan 1, 2011](image)

*Figure 1. Electricity consumption in Sweden during a winter day. (SVK, 2012)*
2.3 Challenges

In order to increase the electric car use in Sweden there are many challenges to meet. It is taken for granted that a car is comfortable and have a reasonable range. In 2011, the petrol cars accounted for about 76 percent of the car fleet (Appendix A, Table 9). Therefore to increase the electric car usage, the electric cars need to aim for the same comfort and range as petrol cars. (Hugosson, 2012)

2.3.1 Charging Infrastructure

An infrastructure with functioning charging system is necessary. Electric charging points should be available at three locations; at home, at work and in public locations. The most common way to charge the electric car is to plug it into a standard electric socket, 230 volt and 10/16 A (Spane, 2010), which is suitable when the car can be loaded when it is not used, such as at home and in workplaces. There are different types of charging, slow charge takes between six to nine hours for full charge. (Jalvemo et al., 2010) Upgraded engine warmers can be used as a charging device, but only for slow charge because of their low power (Spane, 2010). There is also semi-fast charge, which gives three to five times more power than slow charge. Electrical charging points in public places are currently limited to a few places, since the charge needs to be fast and the technology for this is not fully mature. (Jalvemo et al., 2010)
A new solution to this problem is battery stations where battery robots takes out the used battery and replaces it with a full charged battery. The company Better Place demonstrated this in May 2009 at the electric car fair in Yokohama, Japan. Their goal is that it should not take longer to charge a battery than to fuel a traditional car, which was demonstrated at the fair where the charging only took two minutes. The technology will not replace the charging point in terms of everyday use although it will be used for long distance trips when the car has to be charged fast. (Hållén, 2009)

2.3.2 Payment Systems

When electric charging points are located in public places or workplaces it is necessary to have a functioning payment system and there are different possible payment solutions. Payment through an automatic machine is a system where the customer can report which electric charging point they want to use and when to use it. This payment solution is appropriate for parking lots or workplaces, where many electric charging points are at the same place. Another solution is RFID, Radio Frequency Identification, which is a wireless communication between a chip and a reader. The system is enclosed at the electric charging point. The customer can register their identity with for example a card, which can either be a preloaded card or a credit card. A mobile application can also be a solution, either through SMS or a mobile application that communicates with the system inside the electric charging point. Back-office is a solution where the IT system in the electric charging point is integrated with the cars IT system. The company that owns the electric charging point can later debit the customer. Usually at home, the electric cars can be plugged into the standard socket and the payment is charged on the same bill as the household electricity. (Spane, 2010)

2.3.3 Batteries for Electric Cars

Another challenge for electric cars is their capacity to store energy. The energy in batteries is measured in kilowatt-hour per kilogram, kWh/kg. A battery can ordinarily reach 0.140 to 0.170 kWh/kg compared to gasoline that reaches 13 kWh/kg. (Dinger et al., 2010) As a result, the electric car’s range declines extensively. The range of petrol cars is about 700 kilometers per tank, while the range of electric cars in general is about 100 to 150 kilometers per loading (Miljöfordon, 2012a).

There are many compromises in battery technology that need to be developed for the electric car to be competitive against petrol or diesel cars. A battery’s life span is finite and needs to be replaced at regular intervals. The life span depends on the number of charge and discharge cycles and the age of the battery. (Dinger et al., 2010) Batteries for electric cars are guaranteed for eight to ten years (Battery university, 2010a). The relative short lifespan for the battery compared to the lifespan of the car is a problem since the battery is expensive and represents a big proportion of the total price for electric cars (Dinger et al., 2010). Most of the batteries are sensitive for low temperatures because of the conductivity and an increased resistance in the electrochemical reactions at low temperatures. When the temperature is low the battery
also need to heat the coupe, alternatively when the temperature is high the battery is used for air conditioning, which results in a reduced range. (Larsson and Ståhl, 2012)

The safety of batteries is also a factor that needs to be taken into account, since a battery is sensitive for disorders and need to be well placed in the car. A cooling system is necessary to control the generation of heat as well as a functioning overlooking system. (Dinger et al., 2010)

Batteries contain substances that are environmentally unfriendly, such as the heavy metals cadmium and lead (Naturvårdsverket, 2012c). If the batteries are not properly taken care of after use, metals can be spread. Metals that get in contact with soil cannot decompose and thus continue to influence the environment negatively. (Naturskyddsföreningen, 2008) Several heavy metals, especially lead, react very efficient with organic materials resulting in potential damage of microorganisms and small animals (Naturvårdsverket, 2012d). Another disadvantage is that metals are mining products and mining operations can have a negative affect on the environment (Naturvårdsverket, 2011c).

There are different kinds of batteries with varying quality for electric cars. The traditional lead acid batteries are usually used in vehicles when starting the car, but are not optimal for electric cars because of their low energy density. (Dinger et al., 2010)

2.3.4 Types of Batteries

There are two types of nickel batteries, nickel-cadmium (NiCd) and nickel-metal hydrid (NiHM). Nickel batteries can handle low and high temperatures better than lead-batteries and have a higher energy density. The cost is however higher because of the material cost. NiCd can store energy of about 0.045 to 0.080 kWh/kg while NiHM-battery can store energy of about 0.060 to 0.120 kWh/kg (Battery University, 2010b). The NiHM-battery is stable and requires less maintenance than NiCd-batteries, which makes them very popular for electric and hybrid cars, for example Toyota Prius (Larsson and Ståhl, 2012).

Lithium is the lightest of all metals and therefore optimal for batteries in electric cars (Battery University, 2010c). Because of its high energy density and light weight, it is suitable for electric cars. (Larsson and Ståhl, 2012) Lithium ion has an energy density at about 0.110-0.160 kWh/kg (Battery University, 2010b). There are different kinds of Lithium batteries and they have a big potential to store energy in electric cars, but the cost needs to be reduced. (Larsson and Ståhl, 2012)

2.3.5 The Costs for Electric Cars

The initial cost for new electric cars available in Sweden is between 289 900 to 370 500 SEK (Appendix A, Table 6). The price for electric cars is held high because of the high battery prices and the few available models on the Swedish market. In May 2012, there were only five models on the Swedish market (Appendix A, Table 6). The battery prices vary, where lead acid batteries are the cheapest and lithium batteries are the most
expensive. The battery prices are crucial for the cost of electric cars. (Larsson and Ståhl, 2012)

2.4 The Current Development of Electric Cars

Implementation of electric cars in society will require political, administrative as well as financial instruments (Filipsson and Grundfelt, 2009). With the intention to increase the use of electric cars more extensively, it is necessary to expand the charging infrastructure and to create a comfortable situation where the car owners know when and where to charge their vehicle. Many mobile applications have been developed to facilitate the use of electric cars. In 2010, the Finnish electric utility company Fortum launched a free application that retrieves information about available charging stations through a database. (Fortum, 2010) In 2011, Fortum and the City of Stockholm (Stockholms stad) launched the charging points Charge & Drive, which are suitable for public parking lots (Fortum, 2011). Other instruments will also be required to enhance the use of electric cars, such as higher energy and carbon taxes, financial assistance for gasoline stations as well as free parking and charging. Market research has shown that an exemption of congestion charges has been one of the most important incentives for car buyers to choose a green car. (Filipsson and Grundfelt, 2009) The building of a new test project, power supply for electric cars through a rail, started in may 2012. The project was initialised by Elways AB and supported by Energimyndigheten, among others. (Energimyndigheten, 2012)

2.4.1 Government Subsidies

In January 2012, the Swedish Government introduced a “super-green car rebate” to stimulate the market introduction of cars with low emissions of carbon dioxide, known as super-green cars. The super-green car rebate was launched to continue to encourage the transition to a fossil-free fleet by the year of 2030. (Regeringen, 2011b) A super-green car is a car that meets the latest emission regulations by EU, either Euro 5 or Euro 6. The super-green car must also emit less than 50 grams carbon dioxide per kilometre in mixed driving. (Transportstyrelsen, 2011) The vehicle must be registered in Sweden and covered by a EU type approval, which makes electric cars and plug-in hybrids mainly eligible for the rebate. The Swedish Government aims to encourage Swedish car buyers to invest in electric cars by reducing the car fringe benefit (free translation from the Swedish word “Förmånsvärde”) by 40 percent and the size of the rebate is 40 000 SEK for individuals. For legal entities, the size of the rebate is 35 percent of the additional cost for the super-green car or at most 40 000 SEK. The super-green car rebate may not be combined with other types of state or municipal aid in the purchase of super-green cars. The rebate also covers carpools, public sector, cab companies and car rentals and is not limited to a few suppliers. The Swedish Government allocates 200 MSEK for the period 2012-2014 and The Swedish Transport Agency handles the administration of the rebate. (Regeringen, 2011c)
2.4.2 The Additional Costs Compensation by Elbilsupphandlingen

The City of Stockholm and Vattenfall currently run a project named Elbilsupphandlingen that offers financial assistance for a total of 1000 electric vehicles in Sweden. The additional cost compensation (free translation from the Swedish word “Merkostnadsersättning”) applies to both passenger cars and light commercial vehicles and is limited to the selected car suppliers in the project, i.e. Chevrolet Sweden, Citroën Sweden, Mitsubishi Motors Sweden, Renault Sweden and Vantage/Avancee HB. (Elbilsupphandlingen, 2011) The additional costs allowance is also limited to the participating organizations in Elbilsupphandlingen. The rebate is 25 percent of the excess cost of the car or at most 50 000 SEK and is paid in two instalments. In return, the owner of the car must assist in the evaluation of the electric cars by reporting technical data and respond to surveys. The additional cost allowance and the super-green car rebate cannot be combined, as it is contrary to the EU State aid rules (Elbilsupphandlingen, 2012).

2.4.3 Carpools

Carpooling is the self-service, short time rental of cars where the customer can choose the car that suits the customer’s needs. A carpool provides cars with different types of fuel and the user can easily make a reservation online or by phone, depending on the company's flexibility. The customer gains the benefits of having a car without responsibility of ownership and can complement the use of carpooling with other transportation, such as public transport and bicycle. The use of a carpool is suitable for both individuals and companies that travel between 200 and 1100 kilometres per year by car. A carpool provides about one car in ten users but the number varies depending on how frequently the cars are used. (Bilpool, 2011)

There are many advantages of carpooling, such as financial benefits and lower carbon dioxide emissions. (Stockholms klimatpakt, 2012) Insurance, service, parking and fuel are often included in the rental agreement (Bilpool, 2011).

2.4.4 ElBil2020

ElBil2020 is a project in the district of Hammarby Sjöstad, Stockholm, where the vision is that the district will become a world leader the year of 2020 in the use of electric and plug-in hybrids. ElBil2020 is based on the Parliament of Sweden’s decision and goal that the Swedish transport sector will become independent from fossil fuels by 2030. ElBil2020 intend to implement a demonstration program over the coming years. The program is developed collaboratively by ElBil2020, KTH, Elforsk, SP and SICS. The demo program is to establish charging stations in public parking lots and garages and a test panel that evaluates the use of electric cars and to develop business models to attract customers. The program also examines the inhabitants of Hammarby Sjöstad approach to electric cars and their driving habits. (ElBil2020, 2012a) ElBil2020 cooperates with the carpooling company Sunfleet where they offer members of the test panel free
membership for one year in return for an evaluation of a new car model (Elbil2020, 2012b).

2.4.5 Cooperation between Firms

Cooperation between firms is an important part of the establishment of the electric car in our society (Larsson, 2010). In 2007, the Swedish power company Vattenfall initiated collaboration with Volvo where the aim was to test and develop the plug-in hybrid technology. In 2008, Vattenfall started the project “Mini E Berlin powered by Vattenfall” in collaboration with BMW, with the aim to optimize the charging process of the Mini E-cars to take advantage of wind power. The research project is sponsored by BMU, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. Vattenfall has additional cooperation with Nissan and Renault. (Vattenfall, 2012a)

The telecom company Ericsson has developed a platform called ELVIIS, Electric Vehicle Intelligent Infrastructure, in cooperation with Göteborgs Energi, Volvo Car Corporation and Viktoria Institute. The program in the mobile application will allow the driver to control when to charge the electric car. The system will ensure that the charging cost will appear on the car owner’s electricity bill. Using the existing mobile network, the electric car is able to communicate with the power grid and therefore charging can be done specifically by required schedule. This type of coordination of charging will make the network more efficient and sustainable and facilitates the introduction of electric cars in society. (Göteborgs energi, 2012)

2.4.6 Plug-in Hybrid

Due to the obstacles of electric cars mentioned earlier, the establishment of plug-in hybrids, also known as PHEV, is a reasonable and important intermediate step before the society switches from the use of conventional cars to the use of electric cars. (Hugosson, 2012)

A hybrid electric car is a vehicle with two engines; one traditional combustion engine and one electric motor. The batteries in the electric hybrid are charged when used, i.e. when the car is accelerating or decelerating. A plug-in hybrid is developed from a hybrid electric car. The PHEV has a larger battery that can also be charged by connecting a plug to an electric wall socket. (Fortum, 2008) The high battery capacity reduces the fuel consumption and allows the PHEV to have an increased range in comparison to the electric hybrid. (Lucassi, 2009) The charging time of the battery varies depending on the size of the battery. (Vattenfall, 2009)

2.5 Brunnshög

The model is applied on the city district Brunnshög in Lund. Lund is a city with a highly renowned university; a centre for education, research and development. The city with its 111 666 (SCB, 2012b) inhabitants is also known worldwide for several
inventions such as Tetra Pak’s packing solutions and also the Bluetooth, created by Ericsson. (Lunds kommun, Lund i världen) In the north-eastern part of Lund, a new sustainable district is expanding with two research facilities: MAX IV and ESS. Brunnshög must be integrated with the rest of the city and an extension of the public transport system and infrastructure is necessary to manage traffic in a sustainable manner. (Lund NE/Brunnshög, 2012a)

2.5.1 Vision and Goals

In the development of Brunnshög, Lund will turn from a “country town” to an international cosmopolitan city. The vision for Brunnshög consists of three factors:

- The world’s leading research facilities
- A European model for sustainable urban development
- A regional destination for science, culture and recreation (Lund NE/Brunnshög, 2012b)

Lund NE (North East)/Brunnshög focuses on three main topics of particular relevance to sustainable urban development. The first topic is to reduce climate impact caused by urban development, which will contribute to Lund reaching its climate target to reduce its carbon dioxide emissions by half before 2020. The importance of the farmland in Lund is recognized in the planning of Lund NE/Brunnshög and therefore the second topic is to balance the loss of farming opportunities that arises when building the city district. The third topic is to create an environment to maximize impressions and experiences in order to stimulate the human senses. (Lund NE/Brunnshög, 2012c)

The development of Lund NE/Brunnshög is estimated to at least 40 years and includes a lot of planning and several steps. The entire area of Brunnshög comprises 225 hectare and there are plans for many different types of housing, from small first apartments to bigger family apartments and senior housing amongst others. The goal is to build 4000 dwellings, which will create housing for around 7000 people, and workplaces for 30000 people. (Persson, 2010) The western part along the European route E22 will become a work area with offices and the two research facilities, MAX IV and ESS. A goal is also to limit travels to and from Brunnshög by allowing only one third of traffic by car, one third by public transportations and one third by walking and cycling. The inhabitants will also have access to a carpool when needed. (Lund NE/Brunnshög, 2012d)

2.5.2 Tramway

Lundalänken, a busway system, is going to expand and become a tramway. A line between Lund Central station and ESS is going to connect the new neighborhood Brunnshög with the city of Lund and is scheduled for completion in 2015. (Lund NE/Brunnshög, 2012c)
2.5.3 Science Village

Brunnshög will be emerging with two ongoing building constructions, the research facilities MAX IV and ESS. With these facilities, Lund will become a leading city for materials research and life science. There are plans for an area called Science Village around the research facilities where Science Village will become a meeting place with a Science Center, short-time apartments for researchers amongst others. (Persson, 2009)

2.5.4 ESS

In 2014, the construction of the research facility ESS, European Spallation Source, will begin (ESS, 2012a). ESS will be the world’s top materials research facility that uses neutrons to study different types of materials, such as plastic and the use of protein in medicine. The plant will be operational in 2019 and the installation of the research instruments will be completed by the year of 2024. ESS as an organization includes 17 countries and will have its headquarters in Lund. (ESS, 2012b)

2.5.5 MAX IV

Lund University is also planning to build another research facility, MAX IV. The laboratory operated jointly by the Swedish Research Council (Vetenskapsrådet) and Lund University, will replace the existing laboratory consisting of MAX I, II and III storage rings. MAX IV will be the next generation synchrotron radiation facility built in Brunnshög in 2012 and is expected to be completed in 2015. ESS and MAX IV are complementary and will form a leading European centre for materials science, structural chemistry, biology and geophysics. (MAX-lab, 2012)
3. Methodology

The purpose of the model was to calculate the magnitude of emissions of carbon dioxide equivalents, generated from automobiles during one year, by a city or a district. Whenever possible, references and numbers from authorities, agencies and official government reports has been used, for example IVL, Trafikverket, SCB and Elforsk.

3.1 Model Layout

The model calculates the emissions for a future scenario where the user of the model can choose the composition of different automobiles, regarding engine fuel. The amount of emissions for the future scenario is compared with the composition of automobiles for 2012. As for the composition of cars 2012, the model only takes into account petrol, diesel and ethanol cars, since they are the most common types of cars in Sweden and constitutes 98.8 % of all automobiles. (Appendix A, Table 9) The user also gets to choose for which town to perform the calculations, how many people that live in the area, the number of workers there and the fraction of journeys made by car. As a last input parameter, the model needs the user to estimate how many of the inhabitants, living in the city district that also works in that area. This fraction is a necessary input parameter in order to get an accurate number of trips.

3.2 Data

The different parameters that were used in the model are explained below.

3.2.1 The City Parameter

The model can perform calculations for the 12 largest cities in Sweden (SCB, 2011c). For this report the city Lund was used since the calculations were to be performed for Brunnsköld. In the system boundary all journeys to, from and inside the city district was included. This means that all journeys performed by the residents in the area, during one year, was included whilst only the journeys to and from work was included for the people working, but not living in the area. When the case Brunnsköld was simulated, the population in the area was set to 7 000 inhabitants and the people that worked in Brunnsköld was set to 30 000. Among the workers in Brunnsköld, 9.63 % were estimated to live there as well. That fraction was compiled by a number of assumptions. The area of Brunnsköld will be 225 hectare (Persson, 2010), which equals 2.25 km$^2$. If the assumption is made that the city district is circular, the diameter is according to equation (1) calculated to 1.69 km. The longest travel to work for those who live and work in Brunnsköld occurs if they are driving around Brunnsköld in a half-circle. The length of a half circuit is according to equation (2) 2.65 km. The fraction of business related travels below 5 km is 45 percent (Naturvårdsverket, 2012b) and because the length of the longest business related travel for Brunnsköld is 2.65 km, the assumption is made that the fraction of business related travels below 2.5 km 22.5 percent. This value is calculated by dividing the fraction of business related travels with two. In 2010 the population of Sweden was 9 417 000 (SCB, 2010b) and the number of employees were
4 028 500 in 2010 (SCB, 2010a), which represent 0.43 percent. The fraction of workers in Brunnshög that also live there was calculated to 9.63 percent according to equation (3).

\[ A = \pi r^2 \implies A = \pi \left( \frac{d}{2} \right)^2 \implies d = 2 \cdot \sqrt{\frac{A}{\pi}} \]  

(1)

\[ H_C = \frac{\pi \cdot d}{2} \]  

(2)

\[ F_{IW} = \frac{N_{WS}}{N_{IS}} \cdot F_{BR} \]  

(3)

A = Area  
\( d = \) Diameter  
\( F_{BR} = \) Fraction of business-related travels below the maximum distance inside the city district  
\( F_{IW} = \) Fraction of inhabitants living and working in the city district  
\( H_C = \) the length of a half circuit  
\( N_{IS} = \) Number of inhabitants in Sweden 2010  
\( N_{WS} = \) Number of workers in Sweden 2010  
\( r = \) Radius

3.2.2 The Parameter “Fraction Car Journeys”

Calculations can be performed either based on statistical means for the fraction of car journeys in 2012, or based on a vision that is set up for the city district. If the “statistical mean”-option is used, the value is city specific and is set differently depending on the city parameter. Since the vision for Brunnshög is that no more than one third of the journeys are to be done by automobile, the “Vision Brunnshög”-option was used for this study.

3.2.3 The Parameter “Future Car Composition”

When the user is to choose what future scenario to calculate for, the fraction of different automobiles is typed in for electric cars, plug-in hybrids, electric hybrids, biogas, ethanol, diesel and petrol cars. To answer the research questions of this report the future scenario was set to 100% electric cars, since that is a vision for Brunnshög.

3.2.4 The Parameter “Proportion of Emissions Caused by the City District”

It is possible to argue that the entire amount of carbon dioxide equivalent emissions from journeys made to, from and inside a city district, should not be calculated to be “caused by” the city district. The Clinton Climate Initiative, C40 Cities and USGBC (US Green Building Council) refer to a fraction of 40 % of the emissions to be “caused by” the city district (Clinton Climate Initiative, C40 Cities and USGBC, Climate development program). Hence, the model gives the opportunity to choose if the calculations are to be done with the standard-option, that is 100 % of the emissions
caused by the city district, or if they are to be done according to the Clinton Climate Initiative reasoning, by a factor of 0.4. This report includes results calculated using the standard-option, by a factor of 1.

3.3 Calculations

When all the parameters were typed in, the model calculated how many kilometres the residents of Brunnshög and the workers in Brunnshög travel by car each year. The calculation was made according to equation (4) for the inhabitants and according to equation (5) for the workers.

The total distance travelled by the inhabitants of the city district varies from each city and is calculated according to equation (6) when the user has chosen a city. A table of travelled distances by car, for the different cities, can be seen in Appendix A, Table 1. Appendix A, Table 2, shows the mean fraction of the total distance travelled by car for the different counties. As for the distance to work, a fixed mean value for Swedes was used; 16 kilometers one way (Abramowski and Holmström, 2007).

$$T_{DI} = \frac{N_i \cdot D_{Inhabitants} \cdot F}{A_N}$$

$$T_{DW} = \frac{(N_W - (N_i \cdot F_{IW})) \cdot D_{Work} \cdot W_D \cdot (1 - S_D) \cdot F}{A_N}$$

$$D_{Inhabitants} = \frac{D_C}{P_C}$$

$A_N = \text{Average number of people in each car}$

$D_C = \text{Distance travelled by car}$

$D_{Inhabitants} = \text{Distance travelled by each inhabitant of the city district, kilometers per person and year}$

$D_{Work} = \text{The average distance to work travelled by the workers in the city district}$

$F = \text{Fraction of journeys made by car}$

$F_{IW} = \text{Fraction of inhabitants living and working in the city district}$

$N_i = \text{Number of inhabitants in the city district}$

$N_W = \text{Number of workers in the city district}$

$P_C = \text{Fraction of total distance travelled by car}$

$S_D = \text{Fraction of sick days}$

$T_{DI} = \text{The total distance the inhabitants of Brunnshög travel by car each year}$

$T_{DW} = \text{The total distance the workers of Brunnshög travel by car each year}$

$W_D = \text{Number of workdays, when weekends, holidays and vacation is excluded}$

The number of working days was calculated with Excel for 2012, where weekends, holidays and 25 days of vacation were subtracted from the total number of days in one year (Appendix A, Table 7). The fraction of sick days for each town was also taken in consideration and varied as shown in Appendix A, Table 3. The fraction of sick days that was used in this case was the value for Lund at 0.052 (Appendix A, Table 3). A
weighted arithmetic mean value for the number of people in each car at 1.71 has been used. The value represents all travels made by car, both private and work related (SIKA 2009).

3.3.1 Contemporary Scenario

The total amount of emissions caused by the composition of cars in 2012, were calculated according to equation (7).

\[
E_T = (T_{DI} + T_{DW}) \cdot P_E \cdot ((F_P \cdot C_P \cdot E_P) + (F_D \cdot C_D \cdot E_D) + (F_E \cdot C_E \cdot E_E))
\]  

(7)

- \(C_D\) = Fuel consumption for diesel cars
- \(C_E\) = Fuel consumption for ethanol cars
- \(C_P\) = Fuel consumption for petrol cars
- \(E_D\) = Emissions caused by diesel cars, per litre fuel
- \(E_E\) = Emissions caused by ethanol cars, per litre fuel
- \(E_P\) = Emissions caused by petrol cars, per litre fuel
- \(E_T\) = The total amount of emissions caused by composition of cars in 2012
- \(F_D\) = Fraction of diesel cars in Sweden
- \(F_E\) = Fraction of ethanol cars in Sweden
- \(F_P\) = Fraction of petrol cars in Sweden
- \(P_E\) = Proportion of emissions inside the system boundary “caused by” the city district
- \(T_{DI}\) = The total distance the inhabitants of Brunnshög travel by car each year
- \(T_{DW}\) = The total distance the workers of Brunnshög travel by car each year

The fraction of petrol, diesel and ethanol cars were 76.4 %, 17.4 % and 5 % in Sweden by the end of 2011 (Appendix A, Table 9). The share of different types of car can be seen in Figure 3. For petrol and diesel cars, different mean values for fuel consumption were used, depending on for what city to perform the calculations. The fuel consumption for petrol and diesel cars, for different cities, can be seen in Appendix A, Table 4. For ethanol cars, an arithmetic mean value of 84 new ethanol car models in Sweden 2012 were used, considering the fuel consumption. The mean was calculated to 9.46 litre/10 kilometers, using the numbers in Appendix A, Table 5. Emissions caused by petrol cars are 2.66 kg CO\(_2\)e/l, the emissions caused by diesel cars are 2.98 kg CO2e/l and the emissions caused by ethanol cars are 1.19 kg CO2e/l. (Miljöfordon, 2012b) Thus, the amount of emissions per kilometer largely depends on the fuel consumption.
3.3.2 Future Scenario Calculated with Different Electricity Valuation Principles

The choice of electricity production technique is crucial for the result of emissions of carbon dioxide equivalents (Sköldberg et al., 2006) when any future scenario involving electric cars and plug-in hybrids are to be calculated. Fair arguments can be presented for several valuation principles. (SOU, 2008)

For example it is common to argue that when a reform results in an increased electricity demand, the margin valuation principle is appropriate to use. That is because the production techniques that composes electricity on the margin is the last ones used, by definition. In the Nordic countries the margin production is primarily coal condensing power since it is an expensive and variable production technique. (SOU, 2008)

A reform that results in an increased electricity use can however be seen from a long term perspective. If the reform becomes a part of the daily based demand, it may affect the production mix and the average electricity production can, with this perspective cover the increased demand. The character and the extent of the reform are therefore of significance. The law about Emissions Trading can reform the concept with electricity on the margin (Sköldberg et al., 2006). The law regulates the conditions for Emissions Trading and contains rules about permissions to obtain emissions (Riksdagen, 2012). This can force electricity production techniques with small emissions of carbon dioxide to expand and it can make for example coal condensing production to decrease. However there are many coal condensing power plants in Europe, which are likely to remain for a long time. (Sköldberg et al., 2006)

It is possible to argue that electricity on the margin just gives a snapshot perspective of a changed electricity use, suitable to use when calculating for example the effect of putting out a lamp on a cold winter day but not when calculating a long term change.
Counterarguments can also be made against the mean electricity production, such as for example Nordic electricity mix and European electricity mix, referring to the fact that the mean values are retrospective. (Sköldberg et al., 2006)

Modeling has been done by Elforsk to calculate carbon dioxide equivalent emissions caused by electricity production during 2009-2039. The model concerns how the electricity system is powered and what changes that may be done in the northern European electricity system for the following 30 years. The difference between how the electricity system is powered today and the changes that are modeled for in the future constitutes the electricity on the margin for a future perspective for high and modest climate goals. High climate goals are in this case a carbon dioxide price at the range of 40-50 EUR/tonnes of CO\(_2\) and modest climate goals are in this report defined as a carbon dioxide price of 20 EUR/tonnes of CO\(_2\) since those are the values calculated by Elforsk. The northern European system includes all the Nordic countries, Germany and Poland. (Sköldberg and Unger, 2008)

On the other hand, the uncertainty in the development of carbon dioxide prices as well as the impact of Emissions Trading, recommends the snapshot or the retrospective perspective. Hence, three different scenarios for electricity valuation principles were used in this report, the snapshot perspective, the retrospective perspective and the future perspective. The snapshot perspective includes high and low values for electricity on the margin, the retrospective perspective includes Nordic and European electricity mixes and the future perspective includes high and modest climate goals. Thus, the reader can decide what calculation to rely on. The Swedish energy mix is not taken into consideration since a nearly full-scale integration of electricity production in the Northern countries has taken place, as a result of deregulation of the electricity market (SOU, 2008). Because of the electricity grid integration, it is interesting to look at both Nordic and European electricity mixes for mean production, considering the retrospective perspective. (Sköldberg et al., 2006)

The model by Elforsk that generated the values used for the future scenario relies on 6 different calculation scenarios, one reference assumption, one with higher fossil fuel prices, one with a bigger electricity certificate ratio, one with decreased electricity consumption, one with higher prices for emissions of carbon dioxide (45 EUR/tonnes of CO\(_2\)) and one where a limitation of the total carbon dioxide emissions were applied. The model demonstrates that a changed electricity consumption results in big effects concerning the amount of carbon dioxide emissions for most of the calculation scenarios. The calculations have been done in the energy system model MARKAL-NORDIC. Varied prices for emissions of carbon dioxide affects the result largely, where high prices results in lower emissions since the high cost is an incitement for renewable energy, CO\(_2\) separation and CO\(_2\) storage. (Sköldberg and Unger, 2008).

Since the future composition of cars were set to 100 % electric cars for Brunnshög, this report only covers the calculations done for electric cars. Hence, the emissions of carbon dioxide equivalents for a future car fleet of electric cars were calculated
according to equation (8). The variable n stands for the different electricity valuation principles; Nordic electricity mix, European electricity mix, electricity on the margin for high and low values and electricity on the margin by 2030 with high and modest climate goals.

\[
E_F(n) = (T_{DI} + T_{DW}) \cdot P_E \cdot C \cdot E(n)
\]

\(E_F(n)\) = The total amount of future emissions caused by 100 % electric cars, where n is different electricity valuation principles 
\(C\) = Electricity consumption for electric cars 
\(E(n)\) = Emissions caused by electric cars, per litre fuel, where n is different electricity valuation principles 
\(P_E\) = Proportion of emissions inside the system boundary “caused by” the city district 
\(T_{DI}\) = The total distance the inhabitants of Brunnshög travel by car each year 
\(T_{DW}\) = The total distance the workers of Brunnshög travel by car each year

The electricity consumption was calculated by a mean value of the electricity consumption for new electric car models that were available in Sweden 2012, which can be seen in Appendix A, Table 6. The mean electricity consumption of these models was 1.58 kWh/10 km. The amount of emissions caused by electric cars varies largely depending on what electricity valuation principle used. A table of values for the scenarios regarded in this report can be seen in Table 1.

Table 1. The emissions of carbon dioxide equivalents for different electricity valuation principles (Elforsk, 2005).

<table>
<thead>
<tr>
<th>Electricity valuation principle</th>
<th>Emissions [kg CO₂e/ kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snapshot perspective, electricity on the margin, low values</td>
<td>0.400</td>
</tr>
<tr>
<td>Snapshot perspective, electricity on the margin, high values</td>
<td>0.750</td>
</tr>
<tr>
<td>Retrospective perspective, European electricity mix</td>
<td>0.415</td>
</tr>
<tr>
<td>Retrospective perspective, Nordic electricity mix</td>
<td>0.058</td>
</tr>
<tr>
<td>Future perspective, high climate goals</td>
<td>0.150</td>
</tr>
<tr>
<td>Future perspective, modest climate goals</td>
<td>0.600</td>
</tr>
</tbody>
</table>

3.3.3 Primary Energy Factors
To calculate and compare how energy efficient different fuels are, a primary energy analysis has been made. Different primary factors have been used for Nordic energy mix, European energy mix and electricity on the margin for coal condensing power and NGCC (Natural Gas Combined Cycle power plant), that includes losses during the
extraction, refining, production and distribution of the electricity (SOU, 2008). For gasoline and diesel, a primary energy factor for crude oil has been used since both gasoline and diesel are oil products. The primary energy factor for oil products does not include all losses during production of gasoline or diesel and the actual primary factor would consequently be slightly higher. For ethanol, the primary factor have been calculated by a weighted arithmetic mean, according to the shared composition of ethanol production techniques represented in the ethanol available in Sweden 2012. The primary energy factor for Nordic electricity mix, including import and export, was in average 1.49 during 2001-2005. Since the Nordic area at that time was a net importer (SOU, 2008), but in the analysed period will be a net exporter of electricity (Sköldberg and Unger, 2008), the primary factor excluding import and export is used, which is 1.46 (SOU, 2008).

Since the electricity on the margin mainly is produced by coal condensing power in the Nordic region (SOU, 2008), a primary energy factor for coal condensing power was used for high margin values, which is 3.04 (Engström et al., 2009). In a future perspective the electricity on the margin is likely to be produced by NGCC (SOU, 2008), and the value 2.10 (Engström et al., 2009) was therefore used for low margin values. Low margin values are very similar to the values of European electricity mix, which was assumed to be the same, 2.10.

In Sweden, the composition of ethanol is 55% ethanol from sugar cane in Brazil, 12% European ethanol and 20% ethanol from Swedish wheat (Hazard and Henryson, 2009). European ethanol is mostly recovered from wheat (Energimyndigheten, 2011) and the primary energy factor for ethanol was thus calculated for 55% ethanol from sugar cane and 45% ethanol from wheat. The primary energy factor for ethanol from sugar cane is 5.1 and the primary energy factor for ethanol from wheat is 1.87. (Börjesson et al., 2010) The primary energy factor for Swedish ethanol was thus calculated to 3.65 according to a weighted arithmetic mean. For these values an extended system boundary was used. Because of the assumption that all European ethanol is extracted from wheat, the actual primary energy factor is presumably slightly higher than 3.65. The values for each primary energy factor can be seen in Table 2.

### Table 2. Primary energy factors

<table>
<thead>
<tr>
<th>Electricity production</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nordic electricity mix (SOU, 2008)</td>
<td>1.46</td>
</tr>
<tr>
<td>European electricity mix</td>
<td>2.10</td>
</tr>
<tr>
<td>Electricity on the margin, coal (Engström et al., 2009)</td>
<td>3.04</td>
</tr>
<tr>
<td>Electricity on the margin, NGCC (Engström et al., 2009)</td>
<td>2.10</td>
</tr>
<tr>
<td>Oil products (SOU, 2008)</td>
<td>1.20</td>
</tr>
</tbody>
</table>
The primary energy analysis for the present composition of automobiles was done according to equation (9). Primary energy analyses for the future composition of automobiles were done according to equation (10) where \( n \) are the different electricity valuation principles: electricity on the margin for low and high values, Nordic electricity mix, European electricity mix and electricity on the margin by 2030 for high and modest climate goals.

\[
P_{EFC} = \left( F_D \cdot C_P \cdot \left( (P_F \cdot E_F) + (P_E \cdot E_P) \right) \cdot P_{EFO} \right) + \left( F_D \cdot C_D \cdot \left( (P_F \cdot E_F) \right) \cdot P_{EFC} \right) + \left( F_E \cdot C_E \left( (P_E \cdot E_E) + (P_P \cdot E_P) \right) \cdot P_{EFE} \right) \tag{9}
\]

\( C_D \) = Fuel consumption for diesel cars
\( C_E \) = Fuel consumption for ethanol cars
\( C_P \) = Fuel consumption for petrol cars
\( E_D \) = Energy content, diesel
\( E_E \) = Energy content, ethanol
\( E_F \) = Energy content, fame
\( E_P \) = Energy content, petrol
\( F_D \) = fraction of diesel cars in Sweden
\( F_E \) = fraction of ethanol cars in Sweden
\( F_P \) = fraction of petrol cars in Sweden
\( P_D \) = Proportion of diesel in the fuel
\( P_E \) = Proportion of ethanol in the fuel
\( P_{EFC} \) = Primary energy factor, present composition of automobiles
\( P_{EFE} \) = Primary energy factor, ethanol
\( P_{EFO} \) = Primary energy factor, oil products
\( P_F \) = Proportion of fame in the fuel
\( P_P \) = Proportion of petrol in the fuel

\[
P_{EFT} = C_E \cdot P_{EF}(n) \tag{10}
\]

\( C_E \) = Electricity consumption for electric cars
\( P_{EF}(n) \) = Primary energy factor for electricity, where \( n \) is different electricity valuation principles
\( P_{EFT} \) = Primary energy factor, future composition of automobiles, different electricity valuation principles
4. Results

The annual emissions of carbon dioxide equivalents for Brunnhög, for the car fleet of 2012 and the future car fleet, can be seen in Figure 4. The amount of emissions for the future car fleet are calculated from the parameters and values mentioned in the method section, for the different scenarios. Nordic and European electricity mixes are seen as a retrospective perspective, electricity on the margin for high and low values as a snapshot perspective and electricity on the margin according to high and modest climate goals at 2030, as a future perspective.

![Figure 4. Annual emissions of carbon dioxide equivalents for Brunnhög.](image_url)
The emission contrast between the car fleet of 2012 and the future car fleet in Brunnshög can be seen in Figure 5, calculated according to the different perspectives examined in this report.

**Emission contrast between the car fleet 2012 and the future car fleet**

![Bar chart showing emissions contrast between the car fleet 2012 and the future car fleet for Brunnshög.](image)

*Figure 5. Emissions contrast between the car fleet 2012 and the future car fleet for Brunnshög.*
The energy efficiency has, in this report, been measured by how much energy that is needed to drive a car a certain distance. The amount of energy needed for different car types can be seen in Figure 6.

Figure 6 Primary Analysis for different engine fuels
5. Sensitivity Analysis

A sensitivity analysis has been done to evaluate the study's reliability and to identify the key parameters in the model.

5.1 Fraction of Inhabitants Living and Working in the City District

The fraction of inhabitants living and working in the city district do not affect the result of this study of significance. That is because the number of people living in Brunnshög is much less than the number of people working in Brunnshög. Since the fraction strictly can vary between 0 and 1, the inhabitants living and working in Brunnshög was varied between those extremes. The carbon dioxide equivalent emissions were calculated, for the car fleet of 2012, to about 8 500 tonnes and 10 500 tonnes respectively for those values. If there would be a greater number of inhabitants than the number of workers in a city district, the fraction of inhabitants living and working in the city district would be of great significance.

5.2 Fraction of Journeys Made by Cars

The fraction of journeys made by car is of great significance when calculating the amount of emissions. This can be illustrated when changing the parameter “fraction car journeys” from “vision Brunnshög” to a mean value for Lund. According to the vision, one third of the journeys are to be made by car which results in 10 300 tonnes of emissions for the car fleet of 2012. According to a mean value for Lund, 73 % of the car journeys are made by car, which results in 22 900 tonnes of emissions for the car fleet of 2012. Hence, the amount of emissions is doubled when changing the parameter from “vision Brunnshög” to “mean value”.

5.3 Average Number of People in a Car

The average number of people in a car is of great importance for the result as well. The national average for Sweden, for both private and work related journeys, is 1.71. If this number is modified to 1, the amount of emissions increases with 71 %. In contrast, the amount of emissions decreases with 43 % if the average number of people in a car is set to 3.

5.4 Fuel Consumption

The consumption of fuel affects the result since the emissions of carbon dioxide equivalents depends on the fuel consumption. A modelling was done in MATLAB (Appendix B) to calculate for which fuel consumptions the emissions are the same for petrol, diesel and ethanol cars compared to different electricity valuation principles for electric cars. Figure 7 shows the emissions of carbon dioxide equivalents presented for a varying amount of fuel consumption for a petrol car and an electric car. The x-axis beneath the figure presents the fuel consumption for a petrol car and the x-axis at the
top of the figure presents the electricity consumption for an electric car. The amount of carbon dioxide equivalent emissions is seen on the y-axis, which means that the emissions are the same for a petrol car as for an electric car when the graphs are up to each other vertically.

Figure 7. The emissions from carbon dioxide equivalents presented for a varying amount of fuel consumption for a petrol car and an electric car (EC)

Figure 8 shows the emissions of carbon dioxide equivalents presented for a varying amount of fuel consumption for a diesel car and an electric car. The x-axis beneath the figure presents the consumption of fuel for a diesel car and the x-axis at the top of the figure presents the electricity consumption for an electric car. The amount of carbon dioxide equivalent emissions is seen among the y-axis, which means that the emissions are the same for a diesel car as for an electric car when the graphs are up to each other vertically.
Figure 8. The emissions of carbon dioxide equivalents presented for a varying amount of fuel consumption for a diesel car and an electric car (EC)

Figure 9 shows the emissions of carbon dioxide equivalents presented for a varying amount of fuel consumption for an ethanol car and an electric car. The x-axis beneath the figure presents the fuel consumption for an ethanol car and the x-axis at the top of the figure presents the electricity consumption for an electric car. The amount of carbon dioxide equivalent emissions is seen among the y-axis, which means that the emissions are the same for an ethanol car as for an electric car when the graphs are up to each other vertically.
Figure 9. The emissions of carbon dioxide equivalents presented for a varying amount of fuel consumption for an ethanol car and an electric car (EC)
6. Discussion
This section will provide a discussion of the factors that are preventing the introduction of electric cars and an analysis of the results of the report.

6.1 Emissions of Carbon Dioxide Equivalents
As the result indicates, the emissions of carbon dioxide equivalents are, at least, halved in Brunnshög if 100 % electric cars are used instead of the composition of petrol, diesel and ethanol cars that are used in Sweden 2012. The size of the savings depends largely on which electricity principle that is used. The smallest savings are accomplished when the calculations are done according to the snapshot perspective for electricity on the margin with high values. The next smallest savings are made when using the future perspective that includes modest climate goals. The retrospective perspective for European electricity mix results in almost as large savings as the snapshot perspective for electricity on the margin with low values, which means a reduction of about two thirds in carbon dioxide equivalents. The future perspective that includes high climate goals provides the second largest savings and reduces the carbon dioxide equivalent emissions with about 90 %. If the retrospective perspective for Nordic electricity mix is used, the emissions are reduced by almost 96 %. For example, coal condensing power that is frequent in many parts of Europe, generates a much greater amount of carbon dioxide emissions than hydropower, which is frequent in the Northern countries. Thus the advantage of electric cars may depend on where the electric cars are to be used. However it is not as simple as that since other factors mentioned above affects the advantages as well, such as increased electricity consumption, Emissions Trading, and increased grid integration.

When comparing the car fleet of 2012 to a future composition of cars it has to be kept in mind that the fuel consumption for petrol and diesel are mean values for all Swedish petrol and diesel cars whilst the consumption for ethanol and electric cars are mean values for only new cars. That means, according to Figure 7, 8 and 9 in section 5, Sensitivity analysis, that it can be an advantage to use for example a diesel car compared to an electric car in the future, if the fuel consumption for new diesel cars are low enough and if the amount of emissions per kWh are the same for the different electricity valuation principles.

In the model a value of 0.83 litre/10 km was used for petrol cars and 1.58 kWh/10 km for electric cars, which according to Figure 7 means that the electric car emits a smaller amount of carbon dioxide equivalents for all electricity evaluation principles, compared to a petrol car. However, if the consumption for petrol cars decreases, it is possible that a petrol car is preferable to an electric car, depending on what electricity valuation principle that is used. For example, Figure 7 shows that if the petrol consumption would decrease below 0.4 litre/10 km and the consumption would stay the same for the electric car, the amount of emissions are higher for an electric car, using the snapshot perspective for high values.
For diesel cars a mean value at 0.72 litre/10 km was used in the model. Figure 8 shows that the emissions from a diesel car at that consumption were higher than the emissions from an electric car, for all electricity principles. However, if the diesel consumption is below 0.4 litre/10 km and the electricity consumption for the electric car would stay the same, the amount of emissions are the same for the diesel and the electric car. For ethanol cars, a mean value at 0.95 litre/10 km was used in comparison to an electric car with consumption at 1.58 kWh/10 km. For these fuel consumptions, the amount of emissions of carbon dioxide equivalents was higher for the electric car, if the snapshot perspective for high values was used. As for the rest of the electricity valuation principles, the electric car was preferable, from an environmental point of view. However, if the ethanol consumption would decrease, the amount of emissions could be higher using several of the electricity valuation principles for the electric car. Lower fuel consumption levels for petrol, diesel and ethanol cars are not impossible to achieve and it is thus necessary to decide what electricity valuation principle to rely on since that affects when electric cars are to be preferred to other car types.

As the sensitivity analysis displays, several input parameters besides the fuel consumption, affects the amount of emissions. For example, the average number of people in each car affects the result to great extent and hence it is important to car-pool to reduce the emissions of carbon dioxide equivalents.

### 6.2 Energy Efficiency

The primary energy analysis guides in the selection of the most energy efficient type of fuel. However, this analysis takes no account of the climate impact of the different types of fuel. The energy content in ethanol is low which means that an ethanol car requires more fuel to travel one kilometre, which leads to a higher fuel consumption. As Figure 4, section Results shows, a bigger amount of energy is required for petrol, diesel and ethanol cars to travel one kilometre compared to electric cars, regardless of what electricity value principle used, because the combustible fuels have lower energy content than electrical energy. A reason that the energy efficiency of electricity is higher is that the electricity is produced centrally. The usage of energy efficient solutions is desirable due to the increasing demand for energy. Simultaneously, the demand for power will increase in the use of electric vehicles, which is less desirable.

### 6.3 Factors Preventing the Introduction of Electric Cars

In order to increase the use of electric cars, it will be required further work in the development of batteries and expansion of charging points. Other incentives such as legislation and investments will also be needed. If the electric car faces the same expectations for capacity like petrol cars, it will require a significant technology development. If the general public instead are willing to change their car habits, the technology available today for electric cars can be good enough. The range of electric cars are considerably less than for petrol cars, but fully adequate to run for example to work, since the range can reach over 100 kilometres. A natural step in the transition
phase could be plug-in hybrids, in this way the driver can adapt which fuel that are to prefer depending on the distance. This approach can also be useful in association with carpooling, where the customer can choose the car that suits their needs from time to time.

The vision for Brunnhög that 100 percent of the cars in the city district are to be electric cars is perhaps an ambitious vision. A reasonable scenario is to increase the use of electric cars successive during the transition phase. To create a comfortable situation for the car owners, an improved infrastructure is needed. Projects like Elbil2020 and Brunnhög are therefore very important, since the projects can improve the knowledge about electric cars and their impact on society. The projects can also lead to an increased demand of electric cars, which can increase competition between resellers. The cost of the battery and the charging infrastructure constitutes the obstacles of the introduction of electric cars in modern society. It is possible that the cost of electric cars can decrease if the numbers of models of electric cars are increasing.

6.4 Credibility of the Study

When the emissions of carbon dioxide equivalents for the inhabitants of Brunnhög, the workers of Brunnhög living in other city districts excluded, the emissions reaches an amount of 640 kg CO$_2$e/person and year for the car fleet of 2012. As mentioned earlier, the average total number of carbon dioxide emissions from a Swedish person is 5.6 tonnes. Hence, the fraction of emissions caused by the private cars is 11.4 %. This is a reasonable number since the road traffic composes 19 % of the emissions when public transports are included. The model used in this report excludes public transport and the number can therefore be expected to be lower than 19 %. Furthermore, 19 % is a national mean value whilst the 11.4 % is a mean value for Lund, and public transport is more well-used in cities, which means that the fraction of journeys made by car are lower in Lund.
7. Conclusions

The conclusion can be made that the carbon dioxide equivalent emissions would decrease extensively if electric cars were used instead of the composition of cars that are used in Sweden 2012. If the electricity valuation principle that generates most carbon dioxide equivalent emissions is used, that is high electricity on the margin values, the emissions still halves when calculating the environmental effects for Brunnshög. However, the environmental effects depends largely on the fuel consumption for the compared types of cars and what electricity valuation principle that is used. The car fleet of 2012 generated 10 300 tonnes of carbon dioxide emissions. The future car fleet generated 400 tonnes of emissions for Nordic electricity mix, 3 200 tonnes for European electricity mix, 3 100 tonnes for low electricity on the margin values, 5 800 tonnes for high electricity on the margin values, 1 200 tonnes for electricity on the margin at 2030 for high climate goals and 4 600 tonnes for electricity on the margin at 2030 for modest climate goals. Beside emissions of carbon dioxide, the electric car affects the environment negatively, because of their environment unfriendly batteries. However, regarding the local area the electric car is more beneficial, reduced noise, energy efficiency and a reduced oil import dependency, are some of the advantages.

The results show that the electric car is very beneficial from an environmental and health perspective, compared to the composition of cars in Sweden 2012. Although, to increase the electric car usage, there are many obstacles that need to be dealt with. The development of batteries are crucial for the introduction of electric cars, such as improvement in higher energy density and lifespan. The costs of batteries also need to decrease, since it represents a big proportion of the total price for an electric car. Finally, the charging system need to expand, to increase the usability. To achieve a sustainable developement, using electric cars may not be enough since they do not generate zero emissions. A change in the human behaviour regarding the use of cars may thus be needed.
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Interviews

Larsson, Allan, Vice Chairman and project Manager for Elbil2020. Interviewed by Ly, S., Sundin, H., Thell, L. (2011-04-16)
Hugosson, Björn, Unit manager at transport policy WSP Sweden. Interviewed by Ly, S., Sundin, H., Thell, L. (2011-04-16)
Appendix A

Table 1. Distance travelled by car km per person and year for each city (SCB, 2012a)

<table>
<thead>
<tr>
<th>City</th>
<th>Distance travelled by car km per person and year</th>
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</tr>
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<td>Umeå</td>
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<tr>
<td>Örebro</td>
<td>6270</td>
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Table 2. Average distance travelled by car for each county (Abramowski and Holmström, 2007).

<table>
<thead>
<tr>
<th>County</th>
<th>City</th>
<th>Automobile (excl. taxi), km</th>
<th>All vehicles, km</th>
<th>Fraction of distance travelled by car</th>
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Table 3. Fraction of sick days for each city (SKL, 2012)

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Table 4. Consumption for diesel and petrol cars, for each city (SCB, 2011)

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Uppsala 0,07238 0,08346
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Table 5. Fuel consumption for ethanol cars, 84 different models available in Sweden 2012 (Miljöfordon, 2012d).

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<td>VOLKSWAGEN PASSAT VARIANT</td>
<td>1.4 TSI MultiFuel Masters A7 5d Kombi</td>
<td>0.089</td>
</tr>
<tr>
<td>VOLKSWAGEN PASSAT VARIANT</td>
<td>1.4 TSI MultiFuel Masters M6 5d Kombi</td>
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</tr>
<tr>
<td>VOLVO C30</td>
<td>2.0 F R-Design M5 3d Coupé</td>
<td>0.106</td>
</tr>
<tr>
<td>VOLVO S40</td>
<td>2.0 F Classic M5 4d Sedan</td>
<td>0.106</td>
</tr>
<tr>
<td>VOLVO S60</td>
<td>T4 1.6F M6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>VOLVO S60</td>
<td>T4 1.6F Kinetic M6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>VOLVO S60</td>
<td>T4 1.6F Momentum M6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>VOLVO S60</td>
<td>T4 1.6F A6 4d Sedan</td>
<td>0.097</td>
</tr>
<tr>
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<td>T4 1.6F R-Design M6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>VOLVO S60</td>
<td>T4 1.6F Summum M6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>VOLVO S80</td>
<td>T4 1.6F Momentum M6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>VOLVO S80</td>
<td>T4 1.6F Kinetic M6 4d Sedan</td>
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<td>VOLVO S80</td>
<td>T4 1.6F A6 4d Sedan</td>
<td>0.101</td>
</tr>
<tr>
<td>VOLVO S80</td>
<td>T4 1.6FM6 4d Sedan</td>
<td>0.093</td>
</tr>
<tr>
<td>Car model</td>
<td>Details</td>
<td>Consumption [kWh/km]</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Citroen c-zero</td>
<td>E-CVT 5d Kombi-Sedan</td>
<td>0,135</td>
</tr>
<tr>
<td>Mitsubishi iMiEV</td>
<td>CVT 5d Kombi-Sedan</td>
<td>0,135</td>
</tr>
<tr>
<td>Mitsubishi iMiEV</td>
<td>CVT 5d Kombi-Sedan</td>
<td>0,135</td>
</tr>
<tr>
<td>Nissan LEAF</td>
<td>CVT 5d Kombi-Sedan</td>
<td>0,21</td>
</tr>
<tr>
<td>Peugeot iOn *</td>
<td>CVT 5d Kombi-Sedan</td>
<td>0,173</td>
</tr>
<tr>
<td>Mean value</td>
<td></td>
<td>0,1576</td>
</tr>
</tbody>
</table>

- This value are collected from Peugeot website (Peugeot, 2011).

Table 6. New electric car models in Sweden 2012 (Miljofordon, 2012c)
Table 7. Number of work days 2012

<table>
<thead>
<tr>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of days in a intercallary year</td>
<td>366</td>
</tr>
<tr>
<td>Weekends</td>
<td>104</td>
</tr>
<tr>
<td>Swedish public holidays occurred on weekdays (Röda dagar, 2012)</td>
<td>8</td>
</tr>
<tr>
<td>Vacation (Riksdagen, 2011)</td>
<td>25</td>
</tr>
<tr>
<td>Number of Workdays 2012</td>
<td>229</td>
</tr>
</tbody>
</table>

Table 8. The electricity consumption in Sweden during a summer and a winter day in 2011 (SVK, 2012)

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>Electricity consumption in Sweden</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.2011 0:00</td>
<td>16 891</td>
</tr>
<tr>
<td>1.1.2011 1:00</td>
<td>16 482</td>
</tr>
<tr>
<td>1.1.2011 2:00</td>
<td>16 105</td>
</tr>
<tr>
<td>1.1.2011 3:00</td>
<td>15 872</td>
</tr>
<tr>
<td>1.1.2011 4:00</td>
<td>15 783</td>
</tr>
<tr>
<td>1.1.2011 5:00</td>
<td>15 821</td>
</tr>
<tr>
<td>1.1.2011 6:00</td>
<td>16 060</td>
</tr>
<tr>
<td>1.1.2011 7:00</td>
<td>16 329</td>
</tr>
<tr>
<td>1.1.2011 8:00</td>
<td>16 515</td>
</tr>
<tr>
<td>1.1.2011 9:00</td>
<td>16 693</td>
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<tr>
<td>1.1.2011 10:00</td>
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<tr>
<td>1.1.2011 11:00</td>
<td>17 516</td>
</tr>
<tr>
<td>1.1.2011 12:00</td>
<td>17 617</td>
</tr>
<tr>
<td>1.1.2011 13:00</td>
<td>17 709</td>
</tr>
<tr>
<td>1.1.2011 14:00</td>
<td>17 958</td>
</tr>
<tr>
<td>1.1.2011 15:00</td>
<td>18 604</td>
</tr>
<tr>
<td>1.1.2011 16:00</td>
<td>19 538</td>
</tr>
<tr>
<td>1.1.2011 17:00</td>
<td>19 752</td>
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<tr>
<td>1.1.2011 18:00</td>
<td>19 631</td>
</tr>
<tr>
<td>1.1.2011 19:00</td>
<td>19 395</td>
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<tr>
<td>1.1.2011 20:00</td>
<td>18 953</td>
</tr>
<tr>
<td>1.1.2011 21:00</td>
<td>18 449</td>
</tr>
<tr>
<td>1.1.2011 22:00</td>
<td>17 772</td>
</tr>
<tr>
<td>1.1.2011 23:00</td>
<td>17 266</td>
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<tr>
<td>1.8.2011 0:00</td>
<td>9 504</td>
</tr>
<tr>
<td>1.8.2011 1:00</td>
<td>9 384</td>
</tr>
<tr>
<td>1.8.2011 2:00</td>
<td>9 365</td>
</tr>
<tr>
<td>Time</td>
<td>Gasoline</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td>1.8.2011 3:00</td>
<td>9 199</td>
</tr>
<tr>
<td>1.8.2011 4:00</td>
<td>9 274</td>
</tr>
<tr>
<td>1.8.2011 5:00</td>
<td>10 224</td>
</tr>
<tr>
<td>1.8.2011 6:00</td>
<td>11 358</td>
</tr>
<tr>
<td>1.8.2011 7:00</td>
<td>12 325</td>
</tr>
<tr>
<td>1.8.2011 8:00</td>
<td>12 883</td>
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<tr>
<td>1.8.2011 9:00</td>
<td>13 231</td>
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<td>1.8.2011 10:00</td>
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<td>13 151</td>
</tr>
<tr>
<td>1.8.2011 12:00</td>
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<td>1.8.2011 15:00</td>
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</tr>
<tr>
<td>1.8.2011 16:00</td>
<td>12 629</td>
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<td>1.8.2011 17:00</td>
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<tr>
<td>1.8.2011 18:00</td>
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<tr>
<td>1.8.2011 19:00</td>
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<td>1.8.2011 21:00</td>
<td>11 566</td>
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<tr>
<td>1.8.2011 22:00</td>
<td>10 818</td>
</tr>
<tr>
<td>1.8.2011 23:00</td>
<td>10 079</td>
</tr>
</tbody>
</table>

Table 9. Number of private cars in Sweden 2011 (Trafikanalys, 2012)
Appendix B

%utsl\app\ C02e
B95=2.66;
D=2.98;
E85=1.19;
ElNordic=0.058;
ElEurope=0.415;
ElMarginL=0.4;
ElMarginH=0.75;
ElframtidH=0.15;
ElframtidM=0.6;
i=[0:0.1:2];

bensin=i*B95;
diesel=i*D;
etanol=i*E85;
elbil1=(2-i)*ElNordic;
elbil2=(2-i)*ElEurope;
elbil3=(2-i)*ElMarginL;
elbil4=(2-i)*ElMarginH;
elbil5=(2-i)*ElframtidH;
elbil6=(2-i)*ElframtidM;

figure(1)
plot(i, bensin, 'r')
hold on
plot(i, elbil1, 'k.')
hold on
plot(i, elbil2, 'k')
hold on
plot(i, elbil3, 'g.')
hold on
plot(i, elbil4, 'g')
hold on
plot(i, elbil5, 'b.')
hold on
plot(i, elbil6, 'b')

set(gcf, 'Color',[1,1,1])
legend('Petrol car', 'EC Nordic electricity mix', 'EC European electricity mix', 'EC low margin value', 'EC high margin value', 'EC high climate goals 2030', 'EC modest climate goals 2030')
legend('Location', 'NorthWest')

hold off
% 5.4

figure(2)
plot(i, diesel, 'r')  
hold on
plot(i, elbil1, 'k.') 
hold on
plot(i, elbil2, 'k') 
hold on
plot(i, elbil3, 'g.') 
hold on
plot(i, elbil4, 'g') 
hold on
plot(i, elbil5, 'b.') 
hold on
plot(i, elbil6, 'b') 

set(gcf, 'Color',[1,1,1])

legend('Diesel car','EC Nordic electricity mix','EC European electricity mix','EC low margin value','EC high margin value','EC high climate goals 2030','EC modest climate goals 2030')

legend('Location','NorthWest')
%legend('Location','best')

hl1 = line(i,diesel, 'Color','k');
ax1 = gca;
set(ax1, 'XColor','k', 'YColor','k')

xlabel('Diesel consumption [litre/10 km]') 
ylabel('Emissions CO2e [kg/10 km]')

ax2 = axes('Position',get(ax1, 'Position'),'XAxisLocation','top','YAxisLocation','right','Color','none','XColor','k','YColor','k');

hl2 = line((2-i),diesel, 'Color','r','Parent',ax2);

set(gca, 'Xdir','reverse')

xlabel('Electricity consumption [kWh/10 km]')
ylabel('Emissions CO2e [kg/10 km]')

hold off

figure(3)
plot(i, etanol, 'r')
hold on
plot(i, elbil1, 'k.')
hold on
plot(i, elbil2, 'k')
hold on
plot(i, elbil3, 'g.')
hold on
plot(i, elbil4, 'g')
hold on
plot(i, elbil5, 'b.')
hold on
plot(i, elbil6, 'b')

set(gcf, 'Color',[1,1,1])

legend('Ethanol car','EC Nordic electricity mix','EC European electricity mix','EC low margin value','EC high margin value','EC high climate goals 2030','EC modest climate goals 2030')

legend('Location','NorthWest')
%legend('Location','best')

hl1 = line(i,etanol, 'Color','k');
ax1 = gca;
set(ax1, 'XColor','k', 'YColor','k')
xlabel('Ethanol consumption [litre/10 km]')
ylabel('Emissions CO2e [kg/10 km]')
ax2 = axes('Position',get(ax1,'Position'),'XAxisLocation','top','YAxisLocation','right','Color','none','XColor','k','YColor','k');
hl2 = line((2-i),etanol,'Color','r','Parent',ax2);
set(gca,'Xdir','reverse')
xlabel('Electricity consumption [kWh/10 km]')
ylabel('Emissions CO2e [kg/10 km]')
hold off