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A Social Cost-Benefit Analysis of an Electric Vehicle

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Abstract

The Danish government has in the "Energy Strategy 2050" outlined a number of goals for the Danish energy future. The main goals are to increase the share of renewable energy and lower the energy consumption. The accomplishment of the goals should be reached by promoting different energy efficient solutions, such as an electric vehicle. In order to investigate whether the electric vehicle introduced by Renault and Better Place is a possible part of the solution for the society, a Social Cost-Benefit Analysis is conducted. The electric vehicle is compared to a diesel vehicle, as the diesel vehicle is assessed the most environmentally friendly alternative of the conventional vehicles. The analysis is performed as a national assessment in the current settings.

The results of the analysis show that the costs to society of the diesel- and the electric vehicle are nearly the same over the life time of the vehicles, but the electric vehicle is marginally less costly to society. This is based on a difference in the cost structure, where the electric vehicle has a higher initial investment cost, but lower cost of driving. The conclusion of the analysis has however large uncertainties attached, as changing the critical assumptions will affect the results significantly.

The socio economic analysis is put into perspective by analyzing the purchase decision from a private economic point of view. This is done in order to assess whether there is a private economic incentive to purchase the electric vehicle. The analysis shows that the electric vehicle is 22 percent more expensive for the private consumer to purchase. Thus, there is no private economic incentive for purchasing the electric vehicle. The cost difference is mainly due to the operation costs and the time used for switching the battery.

The overall recommendation based on the two analyses is that it would be an option for society to focus on the electric vehicle as a possible part of the solution in order to meet the goals of the Energy Strategy 2050. However, in practice an expansion seems unrealistic in the current settings. Therefore, if the government wishes to meet the established goals by promoting electric vehicles, such as the solution from Renault and Better Place, it is necessary to create better conditions for energy efficient vehicles. It is furthermore concluded that it is necessary to make broad long term political agreements to secure a reliable foundation if investments in new sustainable solution should be accomplished.

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1. Introduction

The growth in the 20th century was mainly driven by the access to cheap and copious amounts of coal, oil and gas (Danish Government 2011). Within the next 25 years the world energy consumption is expected to increase with 33 percent and in the same time the stocks of coal, oil and gas is expected to decrease. Thus it becomes necessary to find new paths and methods in the 21th century, if future growth must be ensured. The Danish government has, with its own words, outlined an ambitious course in the “Energy Strategy 2050”. The goal of the strategy is to be independent of fossil fuel in 2050. In order to meet this goal, the strategy contains several objectives. Two of these objectives are to increase the share of renewable energy to 33 percent in 2020, and lower the energy consumption in 2020 with 6 percent compared to 2006 (Danish Energy Agency 2011a and Danish Government 2011). This ambitious plan is established to ensure that Denmark will be independent of unstable oil nations and fluctuating oil prices in the future. Furthermore, initiatives to encourage development of greener technologies are established with the aim of helping to limit the global heating problems.

Based on the outlined sub-objectives, two main challenges appear; a higher degree of fluctuating supply of energy from renewable energy sources and how to reduce energy consumption. It is therefore necessary to promote energy and economically efficient technologies. In order to meet the goals, it is relevant to look on the transportation sector, as a third of the total energy consumption is used in this sector (Danish Energy Agency 2011b). Furthermore, the main part of the energy used in the transportation sector is extracted from fossil fuel. This has lead to that one of the sub-objectives in the “Energy Strategy 2050” is to obtain 10% renewable energy in the transportation sector in 2020.

If the goals within the transportation sector is to be fulfilled changes are needed, but the changes have to be efficient solutions and not just a changes for its own sake. The government has chosen to focus on the electric vehicle by removing taxes on the vehicles and investing 25 million DKK in charge spots (Ministry of Taxation 2011 and Danish Government 2011). The focus on the electric vehicle is based on the argument that it uses no fossil fuel directly, and therefore will contribute to solving the challenge. However, there are no thorough studies on the socio economic efficiency of an electric vehicle, as the studies are primarily from a private economic point of view or anthropological studies of the user. The upcoming introduction of a new combined product from Renault and Better Place in the autumn 2011 makes it interesting to investigate whether electric vehicles are a suitable solution for society, because the new concept is one of the first real alternatives to a conventional vehicle. It is a real alternative for the consumers, as it deals with the former disadvantages of electric vehicles, such as limited size of the vehicle, large uncertainty on the battery technology and limited driving range. But is the electric vehicle from Renault an economically efficient alternative for both the society and the private consumer, when Renault is the only manufacture of vehicles that is producing electric vehicles with a switchable battery (FDM 2011a).

1.1 Problem Statement

The main purpose of this thesis is to conduct a socio economic evaluation of an electric vehicle and compare it with a conventional vehicle. In order to recommend if the electric vehicle is a possible contribution to the solution of the challenges outlined in the introduction, the analysis will quantify and monetize the impacts associated with both vehicles. To accomplish this, the following research questions will be answered:

- Is it beneficial for the society today if a newly purchased vehicle is electric instead of conventional?

In continuation hereof, to answer if it is realistic that the private consumer has incentive to purchase an electric vehicle:

- Is it beneficial to purchase an electric vehicle from a private point of view?

In order to answer the problem statement the following questions will be investigated:

- What are the socio economic impacts from purchasing and operating a vehicle?
- How are the surroundings affected by the vehicles?
- What are the impacts of a limited driving range of the electric vehicle?
- Are there psychological obstacles for a purchase of an electric vehicle?
- Which socio economic factors are most important in the assessment?

1.2 Delimitations

This thesis is not an attempt to promote or favor electric vehicles, as the aim is to make an unbiased assessment of the alternative vehicles. To the extent it is possible the impacts will be quantified and monetized, but some impacts will only be discussed, due to time and size constraints of this thesis. Even though the latter impacts are not monetized, they will still be discussed and finally considered in the recommendation.

The analysis will be conducted in the current settings, with the initial investment made on the 1st of January 2012. The time frame of the analysis is set to 13 years, as this is the average life time of a vehicle that the Ministry of Transportation (2010) operates with.
It is assumed that the purchase of an electric vehicle will not have an impact on the prices on secondary markets, such as the market for diesel fuel and electricity, since the current market size of electric vehicles is limited. It is assumed that the fuel for the diesel vehicle origins from refined North Sea oil and is produced in Denmark, as this is the assumption made by the National Environmental Research Institute (DMU), in the assessment of the environmental impacts from the production of diesel fuel (Slentø et al. 2010).

In the analysis, Better Place will be perceived as a Danish company, as the largest Danish energy company, DONG Energy, is a major shareholder, and the part of Better Place that operates in Denmark is an independent entity under name Better Place Denmark. If not stated explicitly, Better Place will refer to Better Place Denmark in the succeeding chapters.

2. Methodology

In order to answer the problem statement and the derived research questions from above, there are generally two approaches to consider – a Cost Effectiveness Analysis (CEA) or a Cost-Benefit Analysis (CBA). In the following sections, these two approaches will be described and discussed, and afterwards the best suited approach for answering the problem statement will be chosen.

2.1 Cost-Effectiveness Analysis

A Cost-Effectiveness Analysis (CEA) is a tool for policy makers to choose between different alternatives, either with the goal of maximizing the effects for a given budget or the goal of minimizing the costs for achieving a given effects (Johannesson 1995 and Donaldson 1998). In a CEA it is assumed that each alternative will provide large enough benefits to make it worth implementing, why the focus is on the cost side (Mishan & Quah 2007). The different alternatives are compared using a single effectiveness measure (Boardman et al. 2006). This measure is quantified but not monetized. Based on the costs and the effectiveness measure, the cost-effectiveness ratio of each alternative is calculated. Examples of this could be costs per life saved, costs per accident avoided, costs per ton CO2-emission reduced etc. The alternative with the lowest cost-effectiveness ratio is considered the most efficient.

A general critique of using CEA as a tool to choose between alternatives is that a CEA does not incorporate scales of alternatives (Boardman et al. 2006). Because of the missing consideration of scale, the highest ranked alternative, which is the most cost-efficient, is not surely the alternative with the largest net benefit.

2.2 Cost-Benefit Analysis

A Cost-Benefit Analysis (CBA) is a policy assessment method, in which costs and benefits are included irrespective of to whom they accrue (Boardman et al. 2006 and Johannesson 1995). The purpose of a CBA is to assess all costs and benefits to society from a project. Derived from this assessment it is evaluated, whether the social benefits exceed the social costs. The decision criterion for a CBA is known as the Kaldor-Hicks criterion (Boardman et al. 2006). The criterion states that if the net social benefits are positive, then the society as a whole will gain from adopting the policy, because those who gain will be able to compensate the losers for their loss and still be better off. If the policy under evaluation fulfills the Kaldor-Hicks criterion it represents a potential Pareto improvement.

A CBA relies on assessment of future costs and benefits, which naturally is subject to uncertainty. Thus, a CBA is rather a tool to improve decision making on allocating the society's resources efficiently than it is an exact science (Boardman et al. 2006). In the CBA all costs and benefits are identified, quantified and monetized. Making all costs and benefits comparable in monetary terms is the largest advantage of a CBA, as it allows policy makers to make an informed decision based on comparable measures. On the other hand it is also the largest disadvantage in practice, as it can be extremely difficult and time consuming to assign monetary terms to all costs and benefits. In cases where it is impossible or too time consuming to monetize the impacts, it is important to clearly state the assumptions made and describe the impacts not being monetized (Ministry of Finance 1999)

Many critics of CBA disagree in the utilitarian assumption of potential Pareto efficiency behind the analysis (Boardman et al. 2006). The critics argue that the goal of maximizing the sum of the individual utility in society is not desirable, because it is not possible to make a direct trade-off of utility gains for utility losses, as the marginal utility of income is not constant. Another critique of CBA is the applicability of the analysis due to timing of impacts, trade-offs between the present and the future and methods of monetizing impacts. Other critics criticize the use of CBA because the valuation of costs and benefits rely on the impact on human welfare and not on the well-being of the environment (Pearce 1998).

With these critiques in mind, a CBA is still a powerful tool to support policy makers' decisions, as it is better to make an informed decision than guessing about the future.

2.3 Choice of Approach

According to the 1999-guidelines presented by the Danish Ministry of Finance the choice between conducting a CEA or a CBA depends on the characteristics of the policy under evaluation (Ministry of Finance 1999).

The alternatives under consideration, the purchase of a diesel driven vehicle or an electric vehicle, satisfy essentially the same need – the transportation of persons. Given that both alternatives can sufficiently satisfy the need, it is almost a question of which alternative is most inexpensive. These circumstances point in the direction of choosing a CEA as approach for answering the problem statement.

Even though both alternatives satisfy the same basic transportation need, there are differences in the cost structure. The diesel driven vehicle has larger negative environmental costs than the electric vehicle in terms of higher levels of emissions from driving and production of fuel. On the other hand, the electric vehicle experiences barrier costs in form of less flexibility, due to a lower driving range, as it is necessary to plan the driving route on long hauls in order to pass battery switching stations. Furthermore, it is possible to quantify and monetize most of the costs, and not just compare cost effectiveness measures. The latter arguments point in the direction of a CBA approach.

Based on the description of the available methodology and the discussion above, a evaluation of the cost to society of an electric vehicle compared to a diesel driven vehicle is assessed to be most suited for conducting a CBA, as there are differences in the cost structures of the vehicles, and it is possible to both quantify and monetize these costs.

3. Theoretical Foundations of Cost-Benefit Analysis

The methodology chosen for this study is as mentioned above the approach of CBA. The purpose of CBA is to assess all costs and benefits to society from the project under evaluation. The objective is to facilitate the most efficient allocation of the society's resources. This chapter will elaborate on the theoretically concepts in the approach and clarify the importance and linkage to the project under evaluation. Hence, the section will not describe all matters in the CBA, but it will focus on outlining the most important and relevant aspects in the conduction of a CBA.

3.1 Willingness-to-Pay and Consumer Surplus

When evaluating a project, the appropriate measure of the net benefits for society is the sum of the willingness-to-pay (WTP) of the individuals in society deducted the cost of the project (Boardman et al. 2006). WTP is measured as the maximum amount the individual would be willing to give up in order to obtain the change caused by the project. Alternatively, willingness-to-accept (WTA) is the correct measure, when the project under evaluation reduces the individual's well-being. It is measured as the maximum the individual would require in compensation in order to accept the change (Pearce et al. 2006). The distinction between the measures can be of importance because people have a tendency to demand larger payments to accept small decrements in a good than they want to pay for increments of exactly same size (Boardman et al. 2006). This is almost always true when dealing with a normal good, which is purchased more frequently when income increases (Mishan & Quah 2007).

In practice the consumer surplus is often used as a measure of the impact of the project on consumers. It is the difference between what individuals are willing to pay and what they actually pay. For understanding the term consumer surplus the demand curve have to be examined. The individual demand curve can be interpreted as the most a given person is willing to pay for each successive unit of a good. This implies that a person can be asked how much he or she is willing to pay for one unit of the good; then, what is the most he or she will pay for one additional unit of the good and so on. For a normal good, the different prices of various amounts of the good form a downward sloping individual demand curve, which contribute to the market demand schedule. When a consumer purchases a given amount of the good, he pays the same price for every single unit of good. As his demand curve is downward sloping, he was willing to pay more for the first units of the good than for the last unit. This difference between the WTP and the price can be seen as a surplus to the individual.

The market demand curve, being the horizontal summation of all the individual demand curves, can be assessed as the marginal valuation curve for the society (Mishan & Quah 2007). The reasoning behind the downward slope is the principle of diminishing marginal utility. This entails that each extra unit of the good is valued slightly less than the preceding one and therefore the consumer would be willing to pay less for one additional unit of the good (Boardman et al. 2006). The consumer surplus for all individuals in society can thus be interpreted as the area between the market demand curve and the price line. Hence, the impacts of a project on consumers can be assessed by measuring changes in consumer surplus (Mishan & Quah 2007).

The problem with using the changes in consumer surplus as a measure of WTP is according to Møller and Jensen (2004) that it measures the utility changes along the normal demand curve, also called the Marshallian demand curve. Theoretically, the concepts of Equivalent Variation (EV) and Compensating Variation (CV) would be more correct indicators of the utility changes, because they convert the utility changes into income changes more directly. Both EV and CV use the compensating demand curve, also called the Hicksian demand curve, which states the demand at different price levels holding the utility constant.

EV is defined as the income an individual is willing-to-pay with the original relative price level to avoid the utility loss created by the change. Whereas CV is defined as the income an individual is willing-to-accept with the relative end price level as a compensation for the change.

The concept of WTP, EV and CV can be exemplified in the setting of the project under evaluation. According to Pearce et al. (2006) an individual have an initial state of well-being U_0 which is achieved with the income, Y_0, and an environmental quality level, E_0. Hence, the utility function of the individual is in the initial state

$$U_0(Y_0, E_0)$$

Given that the individual gets the opportunity to improve the environmental quality from E_0 to E_1, e.g. by purchasing an electric vehicle, the improvement gives the individual a new utility function

$$U_1(Y_0, E_1)$$

The interesting part is to measure how much the well-being of this individual is increased by the improvement in environmental quality. This can indirectly be measured as the willingness-to-pay for the change. Hence, the individual should consider two combinations of income and environmental quality

$$U_0(Y_0 - WTP, E_1) = U_0(Y_0, E_0)$$

In order to estimate WTP for the environmental improvement, the individual must obtain the same utility with the new environmental state and the income reduced with the amount of WTP as in the initial state. The willingness-to-pay is thus the individual's compensating variation with respect to purchasing the more environmentally friendly vehicle.

Alternatively, the individuals could be asked how much he or she is willing to accept to forego the improvement in environmental quality and still have the same level of well-being as if the improvement had been implemented. In this case, the willingness-to-accept measures equivalent variation in terms of the value of the change in well-being as a consequence of the improvement in the environmental quality. In the opposite case where the project is resulting in a reduction of well-being the compensating variation is measured by willingness-to-accept and equivalent variation is measured by willingness-to-pay.

Even though EV and CV are more theoretically correct, they are difficult to use in practice, because the compensating demand curve is hard to observe empirically (Møller and Jensen 2004). Based on this argument the changes in CS are used as the indicator of the utility changes in the analysis.

An additional aspect is that one of the main drivers behind introducing the electric vehicle is that it is assessed as a more energy efficient and environmentally friendly vehicle (Danish Government 2011). The willingness-to-pay for an electric vehicle may therefore include either an option value or an existence value bias. The option value bias in the willingness-to-pay is, when people are willing to pay for the option to use a good in the future (Boardman et al. 2006). An example could be that an individual has a value of knowing that by acting more environmentally correct, it will be more likely to have the possibility to visit the Maldives[1] on vacation in the future, given that you see a connection between the human pollution and the global climate change.

The existence value bias is the value that people are willing to pay for the existence of a good even though they never themselves would use it (Boardman et al. 2006). In the case of the example before, it could be that an individual has a value of knowing that the Maldives will endure as a nation.

In the case with the electric vehicle some individuals would purchase it because they favors “green solutions”, some would purchase it because it is cheaper to operate and some individuals will purchase it because it fits their driving needs better etc. There may also be some people that are willing to pay just to have a clear conscience according to future generation’s wellbeing. This value of a cleaner environment in the future is derived as a so called nonuse value, because the individual do not obtain utility from direct use of the resource, but simply from knowing that the resource will exists. In the case of an electric vehicle, the nonuse value will often have an altruistic motivation and thus have a bequest value, because it is directed towards future generations. Therefore, people might be willing to pay something because they get pleasure from knowing that those not yet born will have decent life conditions in the future. A monetization of the option value and existence value of purchasing an electric vehicle will not be included in the analysis, as it is outside the scope of the thesis to conduct a contingent valuation survey, but it will be discussed further in the identification section.

[1] The Maldives is close to be flooded due to rising water levels.

3.2 Producer Surplus and Economic Rent

The literature is dissident in the assessment of whether the producer surplus is comparable to consumer surplus and should be accounted as a gain to the society or not. According to Boardman et al. (2006) the producer surplus is the equivalent to consumer surplus. On the other hand, Mishan (1968) says this is incorrect.

Boardman et al. (2006) argue that just as the demand schedule reflects the consumers' willingness-to-pay for each additional unit of good consumed, an individual firm supply curve reflects the marginal cost of producing. The marginal cost curve assesses the additional cost attached to producing one additional unit of the good. The firm will only produce if the price is above the average cost of producing, why the individual firm supply curve is the part of the marginal cost curve, where the marginal cost is above the average cost. The market supply schedule can be derived as the demand schedule by summing the individual supply schedules horizontally. The producer surplus is then graphically the area above the upward sloping supply curve and under the market price line, which reflects the difference between the price and the marginal cost for the producers.

However, Mishan (1968) argues that in a more generally setting, the producer surplus as the area above the supply curve is not comparable with consumer surplus and in the long run it cannot be seen as a gain. The reasoning behind this is that the economy experiences a scarce amount of input factors such as labor and capital (Mishan and Quah 2007). In order to increase the supply of one good it is necessary to increase the use of input factors. As the amount of input factors is scarce, the input factors must be transferred from another part of the economy, which results in changes in the factor prices. This entails an ambiguous effect on the welfare of society. Furthermore the long-term industry supply curve cannot be interpreted as a net gain by the producers of the good, as each of them under the assumption of perfect competition makes zero profit in the long run equilibrium and the curve can, in fact, be interpreted as a curve of average cost including rent (Mishan 1968).

Only in the case, where the area above the supply curve increases entirely as a consequence of a downward shift of the supply curve, e.g. an improvement in technology, it should be assessed as a benefit (Mishan & Quah, 2007). This is because the shift will not have an effect on factor prices, and would thus be a reduction of the cost.

The correct measure is instead economic rent (Mishan & Quah, 2007). Economic rent is defined as the difference between what the owner of factors of production earns by employing his factors in producing some good and the minimum sum he would accept to keep them there. The relation between economic rent and consumer surplus lies in the concepts of compensating variation and equivalent variation. The compensating variation definition of rent is the maximum sum a factor owner would pay to have full benefit of a price rise. The equivalent variation definition is the minimum sum a factor owner will accept to forgo the benefit of a price rise. The concept of economic rent can be measured as both "types of variation", just as WTP and WTA. Economic rent is comparable with the consumer surplus, as consumer surplus measures the welfare effect, when changing product prices and keeping factors prices constant, whereas economic rent measures the welfare effect, when changing factors prices and keeping product prices constant.

3.3 Price Level

Because the project under evaluation persists over the life time of the vehicle the prices should be expressed in constant terms to make them comparable between the years. Therefore, the prices in the economic analysis are adjusted for the general inflation in the Danish economy. In the analysis the inflation rate is based on the Ministry of Finances ADAM-projections, which are used by the Ministry of Transportation (2010). All prices in the analysis is converted into DKK 2011 prices. The price index can be seen in Appendix 1. As discussed later, the scope of the project under evaluation only extends to a national assessment, why all monetary amounts in the analysis are expressed in DKK.

3.4 Prices

In the conduction of a CBA the identified impacts are converted into monetary terms in order to calculate the net benefits. When converting impacts into monetary terms, the conceptually correct measure of the conversion rate or the accounting price[2] should reflect the price to society (Boardman et al. 2006), meaning that the accounting prices in

[2] Conversion rate and accounting price are used interchangeably

most case do not equal the cash flow from the project. When choosing the conversion rate, there are three available methods (Ministry of Finance 1989): the market price method, the factor price method and the shadow price method. This section will discuss these three methods for monetizing the impacts analyzed later in the thesis.

The 1999 guidelines from the Ministry of Finance generally recommend using the market price as accounting price, when a market price is present (Ministry of Finance 1999). The foundation of using market prices in the CBA is that the total welfare in society depends on the utility of the population. As the consumers are faced with market prices, when they make their consumption choices, the WTP for the good is reflected in the market prices (Ministry of Finance 1989).

When assessing the cost of applying input factors, such as labor, capital or land, the theoretical appropriate price is the opportunity cost of the input factors (Boardman et al. 2006). As the consequences of a policy for the welfare of society is measured as change in WTP, the accounting prices for input factor should reflect this. On the way from producer to consumer, goods are subjects to taxes and duties, and the consumer's consumption choice is thus based on prices including taxes and duties. The Ministry of Finance recommends a general short-cut solution to measure an appropriate accounting price of input factors (Ministry of Finance 1999). The accounting price is found by multiplying the factor price with the net-tax factor (NTF), which is the ratio between the value of the production goods in market prices and the value in market prices excluding taxes and duties. As an approximation for this, the Ministry of Finance (1999) recommends the ratio between the gross domestic product in market prices and the gross value added in factor prices. This is a general approximation as tax-pressure varies across different goods. The 1999-guidelines estimate NTF to be 1.17 in 1999. In Appendix 2 the NTF for Denmark is calculated for 1995 to 2009. In 2009, the NTF was 1.18, which will be used in the analysis.

For internationally traded goods, the 1989 guidelines recommends to use the world market price multiplied with a particular NTF for international traded goods (Ministry of Finance 1989), The argumentation for adding the NTF to the world market price is that importing a good creates a currency expenditure, which gives foreign nations a claim on the society. The claim is met by giving renunciation of goods with similar value, which can be achieved by reducing import or increasing export of other goods. Under the assumption of no trade restriction or antidumping behavior, the difference between the domestic market price and the world market price is due to taxes and duties. As it is unknown which specific goods are exported or not imported, the NTF for internationally traded goods is calculated based on the taxes and duties of all traded goods, and the method is thus a rough estimate of their accounting price. On the other hand, does the 1999-guideslines recommend not distinguishing between the sizes of NTF for nationally and internationally traded goods (Ministry of Finance 1999), which will be the chosen approach in the analysis. The method of using the NTF on imported goods is applied in the case of the battery, as the known estimate of a price is the production cost in a foreign country.

If the price of the good cannot be observed in the market, or when the market price fails to reflect the true social price, the concept of shadow pricing should be used (Boardman et al. 2006). Situations, where the true price to society is unobservable, include the presence of monopolies, externalities, asymmetric information or the pricing of public goods. Even though the market price does not reflect the true social cost, the market price is often used for convenience by practitioners.
In the case of an externality, which is a negative or positive effect on a third party for which no price is charged, the social costs differs from the private costs (Pearce et al. 2006). In relation to a vehicle, driving creates noise, which reduces the utility of the surrounding– both as noise nuisance for individuals and in lower house prices if the house is adjacent to traffic. However, a user of the vehicle does not pay for this. Hence, the private cost of driving is different from the cost to society. To reflect the true cost to society in the conduction of a CBA, it is therefore necessary to incorporate the cost of externalities.

In order to secure that this thesis will be as theoretically correct as possible, the question is throughout the monetization of impacts, whether the observed market price represents the true cost to society.

In addition to assessing the true cost to society another aspect in the CBA theory is relevant. Albeit the market prices reflect the consumer’s utility, there are additional costs to society, when the project involves collection of government revenues through taxes, which is discussed in the next section.

3.5 Transfers and Dead Weight Loss

In the conduction of a CBA it is important to distinguish between what is actually cost and benefits, and what only should be assessed as transfers between different groups in the society. A transfer is an impact that is transferred from one group in society to another group in the society (Boardman et al. 2006). It is called a transfer because it has a net impact of zero from the perspective of the society as a whole. These transfers do not changes the social welfare thus should not be accounted for directly in the CBA.

When a transfer to or from the government is based on tax revenue there is an additionally cost imposed to the society (Boardman et al. 2006). Albeit, the tax revenue imposes a benefit to the government and an apparently identical cost to the consumer there is an additional surplus loss, which is not offset by an equivalent benefit. This loss in surplus occurs because the prices moves away from the competitive equilibrium and towards a higher market price, thereby a deadweight loss is imposed to the society, because it causes the consumers to purchase less output, than they would have done without the tax.

Generally, the deadweight losses generated from raising tax revenue are addressed as the marginal excess tax burden (METB). If a project results in a transfer that increases the excess tax burden, then it is a social cost of the project. If a project allows the government to reduce the excess tax burden it would provide a social benefit (Boardman et al. 2006). The distorting tax effect implies that 1 DKK raised through taxes imposes a cost to the society greater than 1 DKK. In Denmark the distortion loss is estimated by the Ministry of Finance as a loss of 20 % of the amount of the transfer, which also is referred to as the METB (Ministry of Finance 1999). The size of this METB is based on changes in the tax revenue from VAT or bottom-bracket tax (Møller and Jensen 2004). If the size of the tax is substantial larger, then Møller and Jensen (2004) recommend calculating the METB of the transfer from the size of the tax and the price elasticity of demand.

$$METB = \frac{1}{2} \cdot t^2 \cdot \frac{p \cdot q}{1/\eta}$$

Where t is the tax percentage, p is the price exclusive tax, q is the demanded quantity and η is the price elasticity of demand.

Only the transfers that have budget related consequences for the state is subject to METB. Thus, the cost and benefit that are not related to the state budget, such as time savings, noise reductions etc. will not impose an excessive cost to society.

It can be argued that the cost of METB should not be included in the analysis, as the Danish government in 2001 introduced a tax-stop, meaning that the overall tax collection cannot increase (Ministry of Finance 2011). Hence, an increase in the tax collection must result in a tax reduction elsewhere in the economy, and will thereby not marginally increase the transfers. Albeit, the theoretically argument for not including the METB is present, the further assessment will include METB based on the argument that the tax-stop is a political decision and thereby is associated with large uncertainty, especially due to the upcoming election and the general health in the Danish economy, which can create the possibility of a cancelation of the tax-stop. Based on the large uncertainty, a result of the analysis without inclusion of METB will be presented in the scenario analysis in section 10.2.

3.6 The Social Discount Rate

This section will discuss the reasons for using a social discount rate in CBA, and how the appropriate rate in the project under evaluation is chosen. In the evaluation of a project, the project costs and benefits will most often occur in different time periods. In order to make these impacts comparable across time, the impacts of each time period are weighted (Boardman et al. 2006). The weights are known as social discount factors and these are calculated on basis of the social discount rate.

Around the world, governments recommend different predetermined discount rates to be used when conducting a project evaluation. The recommendations by the Ministry of Finance in Denmark, was in 1989 to use a discount rate of 3 percent (Ministry of Finance 1989), while the 1999 guidelines recommend a discount rate of 6 percent (Ministry of Finance 1999). In the UK, the newest edition of the Green Book has lowered the recommended discount rate from 6 percent to 3.5 percent (HM Treasury 2003). Both the Australian and the US Governments recommend using 7 percent as the discount rate

(Australian Government 2010 and White House 1992). The European Commission recommends a discount rate of 4 percent (European Commission 2009).

According to Boardman et al. (2006) there are two main reasons for discounting the impacts of a project. These are the common understanding that resources available today are worth more than the same amount of resources in the future, and because people would rather consume now than in a later period (Boardman et al. 2006).
The first reason is rooted in individuals having the opportunity to invest if the resources are available today, and thereby receive are larger amount in the future. The second reason is that individuals have a time preference for consumption. This can be explained by two factors (Ministry of Finance 1989). Firstly, individuals have pure time preferences, which may be based on an acknowledgement of the limited length of a life time. Secondly, individuals expect larger consumption possibilities in real terms in the future due to economic growth, which does that individuals attach less value to future consumption.

The choice of discount rate in a CBA is an important decision, which is reflected in that it is one of the most debated subjects within CBA (Pearce et al. 2006). According to Pearce et al. (2006), the concept of discounting is incongruent to the focus on sustainability by politicians, as discounting implies a lower weight to impacts in the future. The discount rate is of major importance as the choice of rate single handedly can change the recommendation. The discount rate is hence an obvious candidate for the sensitivity analysis. The following sections will discuss the different possible discount rates and finally choose the appropriate discount rate for the analysis.

3.6.1 Empirically Derived Discount Rates

The empirically derived discount rates are derived from the market. Boardman et al. (2006) and the Ministry of Finance (1999) operate with three possible empirically derived discount rates - the marginal rate of return on private-sector investments, r, the social marginal rate of time preference, p, and the government's real borrowing rate, i. Which of the market based discount rates are the most suitable depends on the financing method used for the project (Boardman et al. 2006 and Ministry of Finance 1999).

If the resources for the project are financed based on taking resources out of the private sector, the use of r is the most appropriate (Boardman et al. 2006). By using the marginal rate of return on private-sector investments as discount rate it is assessed that a public investment should be able to earn an equal or higher return than the private resources the project displaces. To find the marginal rate of return on private-sector investments the best proxy is the real before tax return on corporate bonds (Boardman et al. 2006). In the United States this can for instance be done by using the return on Moody's AAA-rated bonds, which historically yields an estimate of 4.5 percent for r. In Denmark there is almost no tradition of having tradable corporate bonds (Christiansen et al. 2003), why it is not suitable to estimate the rate for Denmark. Instead, the US-proxy is assessed to be useful for Danish conditions.

If the resources for the project are financed based on taxes, instead of taking resources from the private sector, the financing is crowding out consumption instead of investments. Thereby, the apparent rate would be a rate, at which individuals would be willing to postpone small amounts of current consumption (Boardman et al. 2006). This is what the social marginal rate of time preference, p, represents. A proxy for this rate is the real after tax return on savings, which can be found as the real after-tax return on government bonds. Boardman et al. 2006 recommend an estimate of p to be 1.5 percent

Finally, if the project is financed by borrowing from foreign countries, the discount rate should reflect the interest rates paid by the government on the loan. The most appropriate rate in this situation is hence the government's real borrowing rate, i. The rate can be found by calculating the real return on 10-year government bonds. A reasonable estimate of the government's real borrowing rate in the US is 3.7 percent according to Boardman et al. 2006. The rate on a Danish 10-year government bond was 3.13 percent in May 2011 (National Treasury of Denmark 2011).

3.6.2 Theoretically Derived Discount Rates

As capital markets are not perfect due to taxes, transaction cost and asymmetric information, and furthermore individuals have different preferences, inflation expectations and face different tax rates, it is recommended to use another approach than the market based discount rates (Boardman et al. 2006 and Ministry of Finance 1989). The recommended approach in Boardman et al. (2006) and Ministry of Finance (1989) are based on the same model, though they differ slightly. The basis of both models is the optimal growth rate model suggested by Frank Ramsey (Boardman et al. 2006). In this model, discounting is done for two reasons. First of all, society is impatient, which is reflected in pure time preference for consuming now rather than later. The second reason is that society in the long run experiences real economic growth. Because there generally are declining marginal utility of consumption, the society would be better off if consumption were equally distributed over time. Hence by discounting, the future consumption would have a lower weight, and thus lead to recommendations of projects in which the benefits happen in the near future. The equation for the optimal growth rate presented in Boardman et al. (2006) is stated below.

$$p_x = d + e \cdot g$$

Where p_x is the social marginal rate of time preference, d is the pure rate of time preferences, g is the long-run rate of growth in per capita consumption, and e is the rate at which the marginal utility of consumption falls as per capita consumption increases (Boardman et al. 2006). The equation for the social discount rate presented in the 1989-guidelines is stated below.

$$p_x = d + e \cdot (g_c - g_n)$$

Where the difference in the equations are that g_c is the yearly growth in the total real consumption, and g_n is the yearly growth in population (Ministry of Finance 1989). The last term in the latter equation is an approximation of the per capita growth from the first equation, which is a fair approximation at small growth rates. As the population growth in Denmark has been 0.38 percent on average in the period 2000 to 2010 and the total consumption growth has been 1.58 percent in the same period, it is assed that the equations are alike, and thus the first equation will be used to estimate the social discount rate (own calculations based on Statistics Denmark 2011a and Statistics Denmark 2011b).

In order to estimate the optimal growth rate, measures of economic growth, pure time preferences and the rate at which the marginal utility of consumption falls as per capita consumption increases have to be found. For the economic growth, g, Boardman et al.

(2006) recommends using historical per capita data on real consumption expenditures. Generally, it is problematic to estimate future growth based on historical data (Boardman et al. 2006), which is reflected in the large year to year variation as can be seen in Appendix 3. Furthermore, the economy experiences business cycles over time, why growth will be low in some periods and high in others. This leads to that the estimate of future growth rates is sensitive to the time period chosen (Koller et al. 2010). As an example, the average growth from 1969 to 2007 in the real consumption per capita is reduced from 1.62 percent to 1.48 percent if the time period is extended to 2009, due to the financial crisis. Albeit the latter two years have affected the historical growth rate, the longest possible time period is chosen, which is from 1969 to 2009, in order to overcome the business cycle variation. Using a long time period imposes another problem, as it is possible that the average growth rate has shifted through the time period.

With respect to choosing real consumption expenditure as basis for estimating *g*, it is problematic that the national account measure of consumption does not coincide exactly with understanding of consumption held by economists (Boardman et al. 2006). The national account measure includes expenditures on consumer durables, which economists normally regard as an investment. An alternative approach in order to overcome the problem is to use growth in real per capita GDP. The GDP measure includes both private and public consumption, but it also includes investments and net exports, which should not be regarded as consumption. Both long-term growth rates will be presented below and will serve as the lower and upper bound in the sensitivity analysis.

When estimating *g* from the real private and public consumption expenditure the average growth is found to be 1.48 percent while the average growth of real per capita GDP is 1.57 percent for the period 1966 to 2009 (Statistics Denmark 2011b). Despite the problems with the consumption-measure Boardman et al. (2006) still prefer to use this over the GDP-measure. The Ministry of Finance has estimated the average future growth to be 1.52 percent (Ministry of Transportation 2010), which in the light of the above seems as a reasonable estimate to use in the analysis.

The rate, at which the marginal utility of consumption falls as per capita consumption increases, *e*, is uncertain and unknown. According to Boardman et al. 2006, the literature suggests different values between 0 and 2 (Boardman et al. 2006). The 1989 guidelines by the Ministry of Finance believe that *e* is between 1 and 2. As both Boardman et al. (2006) and the 1989 guidelines recommends setting $e = 1.0$, when applying the optimal growth rate model, this value is also chosen in the analysis. In the sensitivity analysis *e* will vary from 0.5 to 1.5.

In the selection of the value for the pure time preference, Ramsey originally advocated for that it would be ethically indefensible to use positive rates (Boardman et al. 2006). Morally, *d* should be set to zero in order to avoid future generations to count less. But setting *d* to zero will lead to very high rate of saving, as the lack of time preferences will postpone more consumption into the future. Hence, the recommendation from Boardman et al. (2006) is to use a value of *d* of 1.0 percent whereas the 1989 guidelines suggest that *d* should have a value between 1.0 percent and 2.0 percent Based on these suggestions, *d* is set to 1.0% in this analysis, with sensitivity analysis at 1.0 percent and 1.5 percent

Based on the above estimates the following optimal growth rate is derived:

$$p_x = 1.0\% + 1.0 \cdot 1.52\% = 2.52\%$$

Based on the lower and upper bound estimates from above, the social discount rate to be used in the sensitivity analysis will be:

$$p_x^{Low} = 1.0\% + 0.5 \cdot 1.48\% = 1.74\%$$

$$p_x^{High} = 1.5\% + 1.5 \cdot 1.57\% = 3.86\%$$

Thus, a social discount rate of 2.52 percent will be used when discounting the impacts of purchasing a vehicle, and a social discount rate of 1.74 percent and 3.86 percent will be used in the sensitivity analysis as an upper and lower estimate, respectively. The discounting procedure will be discussed in the following section.

3.7 The Discounting Procedure

As described in the former section, discounting is used to convert future cost and benefits into present values, generally because individuals prefer to consume now rather than later, and because resources available today is worth more than the same amount of resources available in the future. When investing in a project, society forgoes present consumption in order to enjoy the future benefits from the project. By discounting the future cost and benefits it can be assessed, whether the project can earn a greater return than the resources alternatively could have earned.

In order to evaluate whether a project is beneficial, the most widely applied decision rule is the net present value (NPV) criterion (Boardman et al. 2006). When using this discounting procedure, all the future impacts are converted into a net present value through the formula below.

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1 + p_x)^t}$$

Where B_t is benefits in year t, C_t is costs in year t and p_x is the social discount rate.

Generally, a positive net present value displays that the welfare of society will increase if the project is undertaken, while a negative net present value displays a loss of welfare to society (Boardman et al. 2006). If the net present value is positive, it is, as earlier described in section 2.2, theoretically possible for the positively affected individuals to compensate the losers of the project and still be better off. Thus, a project should only be adopted if the net present value is positive.

In the analysis of the diesel and electric vehicle, the focus is only on the cost side, as it is assumed that the utility of transportation is large enough to secure a positive net present value. If the net present value is negative the consumer will not conduct the purchase. Hence, the alternative with the lowest cost to society is considered the best solution to satisfy the transportation need.

Despite the convenience of the NPV procedure, Mishan and Quah (2007) argue that there is a problem with using a single interest rate when discounting all flows. This is due to that parts of the benefits accruing from the initial investment are consumed, while other parts are reinvested (Mishan and Quah 2007). Because the rate of return on investment and the rate of time preference are different, as discussed earlier, the parts of the benefits should be discounted with different discount rates.

To cope with this reinvestment problem, Mishan and Quah (2007) proposes the Compounded Terminal Value (CTV) method, where all flows are compounded forward to a future terminal date instead of backwards to a present date. The flows are compounded with different rates depending on whether they are consumed or reinvested.

Boardman et al. (2006) have a different approach in dealing with the reinvestment problem. The use of resources that displace investments should be treated different than resources that displace consumption, as investments create a stream of future benefits, whereas consumption provides an immediate benefit. If all resources used in the project displaces investment, then the appropriate discount rate would be the return of private-sector investment. On the other hand, if all resources used in the project displaces consumption, then the appropriate discount rate would be the social marginal rate of time preferences, as it should reflect the rate at which individuals are willing to postpone consumption.

The shadow price of capital method recognizes this, as it converts investment flows into consumption equivalents by multiplying investment flows with the shadow price of capital, θ (Boardman et al. 2006). The shadow price of capital is defined as:

$$\theta = \frac{(r+\delta)(1-f)}{p - r \cdot f + \delta \cdot (1-f)}$$

Where *r* is the net return on capital after depreciation, *p* is the social marginal rate of time preferences, δ is the depreciation rate of capital invested and *f* is the fraction of gross return that is reinvested.

Applying the shadow price of capital method is divided into four steps (Boardman et al. 2006). Firstly, the impacts in each time period are split into those that affect consumption and those that affect investment. Secondly, the investment flows in each time period are converted into consumption equivalents by multiplying with θ. Thirdly, the consumption flows and consumption equivalents are added together. Lastly, these impacts are discounted with the social discount rate.
To be able to apply the method, it is necessary to calculate a numeric value of θ. From the above equation it is seen that the values of *r*, *p*, δ and *f* are needed. The value of *r*, the net return on capital after depreciation, can be evaluated as the return on private investment, and has thus already been discussed in section 3.6.1. It was recommended set-

ting r equal to 4.5 percent based on AAA-rated corporate US bonds. The social marginal rate of time preference, p, was in section 3.6.2 derived from the use of the optimal growth rate model to be 2.52 percent

As a value for the depreciation rate of capital, δ, Boardman et al. (2006) recommends using 10.0 percent based on work of Hulten and Wykoff. In order to estimate the rate of depreciation the "Consumption of fixed capital" and the GDP has been found in Statistics Denmark from the period 1966 to 2009 (Statistics Denmark 2011c). The average ratio over the years is 13.62 percent in Denmark. As the standing in this CBA only includes individuals living in Denmark, the Danish estimate will be used in the calculation of θ.

Boardman et al. (2006) suggests to use the ratio of real gross fixed investment to real GDP, in order to find the numeric value of the gross investment rate, f. This yields an estimate of 17 percent on US data, while it results in an estimate of 20.20 percent when applied to the 1966 to 2009 Danish data (Statistics Denmark 2011c). The Danish estimate is again chosen because of the definition of standing in this thesis.

Compiling the estimates from above yields the following shadow price of capital:

$$\theta = \frac{(4.5\% + 13.62\%)(1 - 20.20\%)}{2.52\% - 4.5\% \cdot 20.20\% + 13.62\% \cdot (1 - 20.20\%)} = 1.16$$

Hence, all impacts which are indentified as crowding out investment will be multiplied with 1.16 in the later stage of discounting the impacts.

After having discussed the theoretical foundations of a CBA, and determined the net tax factor, the social discount rate and the shadow price of capital, the following chapter will present the framework of the analysis.

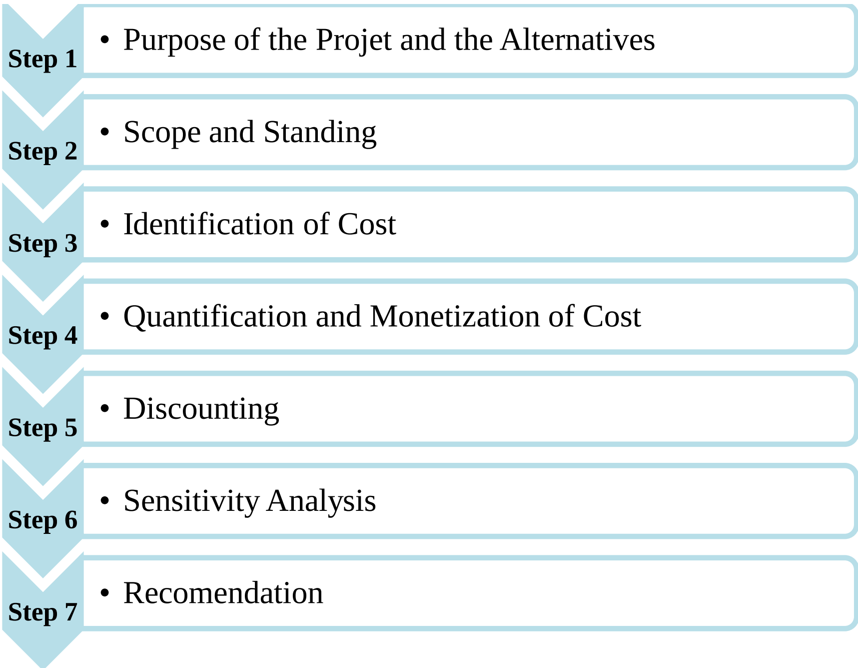
4. The Analytical Framework

This section will provide the analytical framework chosen in order to make a clear structure throughout the analysis. By applying a structured approach the risk of redundancy in discussions and the risk of overlooking central elements in the analysis, will be minimized. Furthermore, the thesis will be more reader-friendly. The framework is based on a combination of the recommendation of Boardman et al. (2006) and the 1999 guidelines from the Danish Ministry of Finance.

The Ministry of Finance (1999) suggests four phases for conducting a CBA, whereas Boardman et al. (2006) has a higher level of detail in the recommended nine step approach. Basically, these two approaches contain the same content, but with a different level of abstraction.

With inspiration from the above mentioned, it is assessed that the following seven step approach is most suited for the purpose of conducting a CBA of an electric vehicle.

Figure 4.1: Analytical Framework of the Cost-Benefit Analysis



Source: Own creation based on Boardman et al. (2006) and Ministry of Finance (1999)

The following chapters consist of two separate CBA, where the first analysis assesses the diesel vehicle Renault Megane dCi 90 FAP and the second analysis assesses the electric alternative Renault Fluence Z.E. The reasons for choosing these vehicles will be discussed in the succeeding chapter.

5. Purpose of the Project and the Alternatives

This chapter will firstly assess the purpose of the project and the alternatives under evaluation. Afterwards will the combined product from Renault and Better Place be presented and discussed. In the end of this chapter it is described, which setting the electric vehicle is introduced into, and thereby how the Danish electricity system works and which challenges the system is expected to experience in the nearby future.

As aligned in figure 4.1 the first step in the conduction of a CBA is to define the purpose of the project and illustrate the alternatives. In a CBA, the net social benefits of investing resources in a particular potential project are compared to the net social benefits of another project that would be displaced if the project under evaluation is preferred. The displaced project is normally the counter-factual or status quo, thus the situation where no change is made. Sometimes doing nothing is not an alternative and then it should be evaluated relative to another alternative (Boardman et al. 2006). In this CBA, the two alternatives are compared to each other, since the status quo where the individual has no vehicle does not provide a suitable solution to the transportation need.

The purpose of the project under evaluation is to analyze the feasibility of one of the cornerstones in "Energy Strategy 2050". The energy strategy aims to introduce a gradual adoption of sustainable energy in the transportation system, implying that Denmark in 2050 will be independent of fossil fuel and unstable oil nations (Danish Government 2011). The energy consumption in Denmark is divided into four areas; Household, Trade and Service, Production and Transportation. The two largest energy consumers are Household and Transportation, which both has a share of approximately on third (Danish Energy Agency 2011b and Danish Government 2011). Hence, the transportation sector is an important area of interest, if the goals are to be reached.

5.1 The Alternatives

This CBA focuses on the area of transportation and evaluates the sustainable alternative, the electric vehicle. Even though, the motivation behind focusing on the electric vehicle is based on the underlying believing that it is more sustainable and energy efficient than the conventional vehicle, it is important to emphasize that the basic need the alternatives have to cover, is the transportation of persons from one place to another.

The electric vehicle has been chosen from the gross group of renewable energy (RE)-alternatives, which include electric, plug-in hybrid, hydrogen and bio-fuel driven vehicles. Albeit, the electric vehicle has been chosen, it is not to be said that the electric vehicle is the best alternative with respect to achieving the goal in 2050, but it is the alternative which the public and the private companies as DONG Energy and Better Place have most focus on at the present. The alternative is chosen to be a diesel vehicle, because it is considered the most environmentally friendly alternative of the conventional alternatives, petrol or diesel, as the diesel version are ranked A in energy class, whereas the petrol versions are ranked C or D (Renault 2011a). Furthermore, the analysis could have included more alternatives than the electric and diesel vehicles, but given the limited size of this thesis, the analysis would have been more superficial.

The Reanult Fluence Z.E electric vehicle (from now on Renault Fluence) is chosen based on the arguments that it is one of the newest versions of the electric vehicles. It can be seen as a direct substitute to the conventional family vehicle, due to the size and performance of the vehicle. Furthermore, it is the first electric alternative that deals with the main barriers associated to an electric vehicle; the flexibility problem in connection to the range of the battery and the uncertainty of the battery. Renault and Better Place tries to handle these barriers by installing switching stations to increase the range of the vehicle, and introduce leasing of the battery to remove the uncertainty associated with the development in the battery technology.

Since the electric vehicle under evaluation is the Renault Fluence, the alternative vehicle needs to be the most comparable vehicle on the Danish market. By comparing characteristics of different Renault models, the Renault Megane dCi 90 FAP (from now on Renault Megane) has been chosen. The two vehicles are the closest possible approximation of the same vehicle but with different motor types. This can be seen from the specifications below.

Figur 5.1: Vehicle specifications of 2011 models

	Renault Megane		Renault Fluence	
Import Price	91529	DKK	167200	DKK
Price incl VAT & excl Tax	114411	DKK	209000	DKK
Price incl VAT & Tax	245100	DKK	209000	DKK
Integrated Navigation	7899	DKK	-	DKK
BHP	90/66	BHP/kW	95/70	BHP/kW
Engine	1.5 dCi		24	kWh
Moment	200	Nm	226	Nm
Wheelbase	2641	mm	2696	mm
Length	4295	mm	4820	mm
Width	1808	mm	1882	mm
Height	1471	mm	1520	mm
Weight	1290	kg	1600	kg
Range per Fuel unit	22.70	km/liter	4.44	km/kwh
Fuel tank	60	liter		
Range	1362	km	160	km
Top speed	180	km/h	135	km/h
Life time	13	year	13	year
Boot space	405	liter	300	liter

Source: Overgaard (2010), Renault (2009), Bilzonen.dk (2011) Bilbasen.dk (2011)

The timeframe of the project is set to be the lifetime of the vehicles. Hence, the evaluation is made within the current settings to investigate if it in the present is beneficial for society that an individual chooses to purchase an electric vehicle instead of the diesel driven alternative. As mass produced electric vehicles are a rather new phenomenon, there is limited experience with the life time of the vehicles. Hence, it is chosen to apply the same life time for both vehicles. The life time of the two vehicles is set to be 13 years, which is the average life time of a Danish vehicle (Ministry of Transportation 2010). If the lifetime of the two alternatives had been different, there would have been two approaches to handle it depending on the chosen perspective (Ministry of Finance 1999). For the vehicle with the longest lifetime, a scrap value as a positive contribution in the CBA could have been included. Otherwise it could have been assumed that there would have been made a reinvestment in the vehicle with the shortest lifetime. Thus, the reinvestment would be another cost in the CBA. Since the timeframe is set to be the whole lifetime of the vehicles, there will be neither scrap value nor reinvestment included in the evaluation.

5.2 The Product from Renault and Better Place

If the consumer chooses to purchase the Renault Fluence, Better Place will provide the electricity and the battery (Better Place 2011a). The price Better Place charges depends on how many kilometers the consumer expects to drive. Included in the price are free electricity up to the chosen kilometer level, unlimited number of battery switches, a navigation system and 24 hour roadside assistance. There are two main advantages for the consumer of this arrangement compared to other electric vehicle solutions. Firstly, the consumer does not carry the risk of a worn out battery, as it is possible to change the battery to another one at the battery switching stations. Secondly, as new battery technology will develop, the consumer can get access to the new batteries without having to make a new investment, as Better Place continuously will need to replace the stock of batteries.

At the present, Better Place is the only supplier of battery switching stations, and the consumer is obliged to purchase the Better Place's subscription and a home charge spot. Thereby the consumer has an extra price attached to the purchase of the Renault Fluence, which is illustrated in the figure below.

Table 5.1: Prices of the Better Place Subscription, in DKK 2011 prices.

Monthly Subscription	Annually km Driven	Fee per Excess km Driven	Establishment of Home Charge Spot
1495	Up to 10,000	2.24	9,995
1695	Up to 15,000	1.7	
1895	Up to 20,000	1.42	
2495	Up to 30,000	1.25	
2995	40,000 and up	-	

Source: Better Place (2011a)

As can be seen in the table, the consumer has a fixed initial fee from the establishment of the home charge spot, and fixed monthly fee based on the chosen number of kilometers. If the actual kilometers driven are above the chosen number, an excess fee per extra kilometer driven is paid.

Furthermore, there is a connection fee that the buyer has to pay to the local net-company in order to install the charge spot (Better Place 2011b). The price varies within the interval DKK 0 to DKK 10,000 depending on the geographical location (Better Place

2011c). The price variations are illustrated in Appendix 4. Since the electric vehicle primarily is a city vehicle the connection fee is set to be DKK 2,000, which is the upper bound of the interval in the largest cities. If the buyer wants to install an extra charge spot, Better Place charges an additional fee of DKK 195 plus the DKK 9,995 for the charge spot. If the buyer decides to move, Better Place charges DKK 9,995 to removed the old charge spot and install the new. As an additional element of the subscription with Better Place the buyer receives an intelligent navigations system integrated in the Renault Fluence. If the desired route exceeds the capacity of the battery, the navigation system plans the route to include potential battery switches or charges at charge spots. The battery switches will be carried out in one of the 19 full automatic battery switching stations (Better Place 2011d). The location of the stations can be seen in Appendix 5. Furthermore the government plans to use 25 millions on setting up public charge spots in Denmark (Danish Government 2011). A quick recharge approximately takes 15 minutes and will add 60 to 100 kilometers to the driving range (FDM 2011b).

5.3 The Electricity System and Production in Denmark

Today, the Danish electricity system works in the manner that production follows the consumption (Energinet.dk 2010a). The electricity system is based on a transmission net, which goes from high voltage on 400-132 kV to 60-30 kV and to middle voltage on 20-6 kV. The transmission net is used to transport the electricity from the producer to the local net-company. The system furthermore has a distribution net, the low voltage net on 0.4 kV, which distributes the electricity to the consumers. The reason for the different voltage levels is that high voltage is suitable for transport over long distances, while low voltage is suitable for directly delivery to the local net-companies ((Danish Energy Association 2010a). The structure of the system can be seen in Appendix 6.

The Danish electricity market has been liberalized since the 1th of January 2003 (Gyldendal 2011a). Hence, the consumer can choose among different suppliers or local net-companies, when they are buying their electricity. The Danish transmission net is connected to Sweden, Norway and Germany and most of the electricity is traded on the Nordic electricity market NordPool. The market can be divided into two parts, the elspot market and the power regulation market. The elspot market is controlled by NordPool. The following day's hour price of electricity on the market is determined one time during the day and is based on the supply and demand (Danish Transport Authority

2010). The spot price, the consumer pays in the commercial electricity price is a non-weighted average of the hour price throughout the calendar year. Because the price of electricity varies very much over the year, week and day the real cost for the consumer and producer deviate depending on the user profile of the buyer. Typically the price will be high when demand is high and vice versa (Danish Energy Agency 2010). The second part of the electricity market is the power regulation market, which handles the fluctuating supply from wind energy by resizing the production up and down on the power plants in order to meet the demand (Danish Transport Authority 2010).
The electricity production in Denmark has the following distribution among forms of production.

Figure 5.2: Danish Electricity Production in GWh, 2009

Production Form	West-Denmark	East-Denmark	Total
Thermic production with non RE-Fuel	70.5%	73.7%	71.5%
Wind Power	22.5%	13.7%	19.6%
Thermic production with RE-Fuel	6.9%	12.6%	8.8%
Water and Sun power	0.1%	0.0%	0.1%
Total production	**22,739**	**11,551**	**34,290**

Source: Own calculations and Energinet.dk (2010b)

As aligned in the figure above the 71.5 percent of the Danish electricity production comes from the production with non RE-Fuel, which consists of coal, oil and natural gas. In 2009, the central power plants produced 61 percent of the total electricity production in Denmark. This production was based on 75 percent coal, 13 percent natural gas, 5 percent oil and 7 percent from other sources (Danish Energy Association 2010a).

In the future, it is expected that a larger part of the production of electricity will come from fluctuating production forms, such as wind power (Danish Government 2011). This expected increase will demand much more flexibility in the Danish electricity system, because the electricity supply will be more exposed to the weather, time of year or day etc. Today, the electricity production adapts to the electricity consumption, but in the future, where a larger proportion of the production will be fluctuating, the consumption must be adapted to the production level. Thus, electricity based technologies such as heat pumps, heating elements and electric vehicles can perhaps be a solution, where the more fluctuating production can be absorbed. Though new consumption technologies can be one solution, they do not complete fulfill the storage requirements. The intelligent electricity net, Smart-Grid, are therefore being introduced as a opportunity to integrate all attached producers' and users' behavior, so the electricity system becomes much more effective and efficient. The intelligent net works in the manner that it has an intelligent connection-box with a timer, which entails that the use of electricity can be removed from the high demand periods. (Energinet.dk 2010a). Hence, the benefits to society from the intelligent net are that the fluctuating electricity can be used better and thereby exploit the current transmission and distribution net more optimal. This intelligent net will benefit the consumer in the manner that they will be offered a lower price of electricity in e.g. the night times, where the supply is much larger than the demand (Energinet.dk 2010c).

As the situation is right now, the owner of the Renault Fluence will not benefit from this because they are paying a fixed price to Better Place, no matter when they are charging the vehicle. This can create moral hazard, meaning that the consumer will behave societal inefficiently by not charging the vehicle, when the demand for electricity is low. It is therefore needed to create an incentive for the consumer to charge at the right time, when the Smart-Grid is introduced.

6. Scope and Standing

As the alternatives and definition of the project have been determined, the next step in the conduction of the CBA is to determine whose willingness-to-pay that should count in the socio economic evaluation (Boardman et al. 2006). The willingness-to-pay and willingness-to-accept are summed across all individuals, hence, the society must be defined as the sum of all individuals.

The geographical boundary of the analysis defines the scope of society. Only the impacts of individuals within the scope are included in the analysis (Pearce et al. 2006). This is, according to Boardman et al. (2006) known as the issue of standing, which deals with the size of society. The scope of society can either be regional, national or global. The distinction becomes relevant, when the project under evaluation have impacts that spill over national borders. Usually CBA studies operate with national boundaries, but there might be cases where global boundaries are more suitable (Pearce et al. 2006).

In the context of the project under evaluation, it can be discussed whether the definition of society should be national. The primary argument for a national level is that it is the Danish ambition to be independent of fossil fuels in year 2050, which has increased the focus on electric vehicles in Denmark. Furthermore, most of the environmental improvement that can be expected from a development towards more electric vehicles can be seen as local effects. Most pollution improvements are located in the cities, where the air will be cleaner and the noise level lower.

Albeit, many of the environmental improvements are located within the national borders, the improvement in pollution level can also point towards a more widely definition of the boarders. This argument is based on that sulphur and nitrogen are transboundary pollutants and thereby will other countries besides the polluting country also be affected of e.g. acid rain. Another aspect is the Danish electricity market is connected to Sweden, Norway and Germany. Thus, any change in Denmark will also affect those countries and vice versa. Albeit, the electric vehicles are sold in Denmark, the battery switching stations are located in Denmark and the vehicles use Danish electricity both Better Place International and Renault is international firms, which also can point towards a more global view.

Even though the Danish electricity market in praxis is connected to the countries surrounding Denmark and that there can be environmental arguments for a more widely definition of the society, the definition will be at the national level since the main effects are attached to the Danish population. Hence, this CBA will only quantify and monetize the impacts that occur to individuals living in Denmark.

7. Identification of Cost

The next step is to outline all the relevant impacts as cost and benefits. The only impacts of interest are the ones that affect the utility of the individuals with standing (Boardman et al. 2006, p. 10). Thus, impacts that do not have any value to human beings are not included. Hence, in order to treat something as an impact, there have to be a cause-and-effect relationship between the physical outcome and the utility of the individual with standing.

The economic evaluation consists of two independent CBA's which is compared afterwards to assess, which is the less costly alternative. The first CBA considers the Renault Megane diesel vehicle and the second CBA consider the Renault Fluence electric vehicle. The cost and benefit attached the two CBA's are aligned in figure 7.1.

Figure 7.1: Costs and Benefits of the vehicles

Cost	Benefit
• Investment • Operation • Maintenance • Environmental Impact • Noise • Switching Time/Refuling time • Perception Barrier • METB	• Utility of Transportation

Source: Own creation

Within the limitations of this master thesis, it is not possible to conduct a contingency survey to determine the utility of transportation for a diesel and an electric vehicle. However, if the consumer chooses to purchase a vehicle, it is implicitly that the utility of transportation will exceed the costs attached to the vehicle. Based on this argument, the following sections will discuss the specific cost attached to the two alternatives.

7.1 The Diesel Vehicle

The impacts in form of cost attached to the Renault Megane diesel vehicle are identified in the following subsections. The subsections will describe the costs and discus the relevance of each cost.

7.1.1 Investment

The purchase of the diesel vehicle is conducted in order to fulfill the need of transportation. When evaluating the costs to society associated with purchasing and afterwards operating a diesel vehicle, the initial investment in the vehicle is the main cost. The cost of investment consists of the price of vehicle and the equipment required in order make the vehicles comparable.

The price of the vehicle can be subdivided into three elements: the price without taxes, VAT and a registration tax. To make the alternatives comparable, it is necessary to install an integrated navigation system in the diesel vehicle.

The purchase of the vehicle is assessed as an investment good, because the vehicle has a high initial value and a relatively long life time. The investment is a onetime cost, which falls in the beginning of the evaluation period.

7.1.2 Operation

The largest operation costs for the Renault Megane is the diesel fuel needed in order to make the vehicle drive. The fuel cost is dependent on the kilometers driven.

Along with the cost of fuel, the operation costs consist of a biannual fuel consumption tax, which depends on the level of fuel consumption of the vehicle (Ministry of Taxation 2010). The longer a vehicle can drive on a liter fuel, the less is paid in tax.

Furthermore, the operation costs include a yearly cost to road assistance, as this is included in the Better Place solution.

7.1.3 Maintenance

The maintenance cost attached to the conventional diesel vehicle is divided into three parts; reparation and maintenance of the vehicle, motor oil and tires (Danish Transport Authority 2010). The reparation and maintenance can be divided into the engine, comforting parts, safety parts and technical components, such as steering system, wheel suspension, shock absorber, suspension and brakes. The maintenance cost is depending on the kilometers driven and will occur over the whole life time of the vehicle.

7.1.4 Environmental Impact

The environmental impacts of driving a conventional diesel vehicle can be divided into two parts. The first part is the environmental impact from the production of the diesel, and the second part is the environmental impact from the combustion in the diesel engine.

As stated earlier in the delimitations section, it is assumed that the fuel for the diesel vehicle origins from refined North Sea oil and is produced in Denmark. Diesel fuel is made from raw oil, and in Denmark it is produced at two refineries in Fredericia and Kalundborg, respectively.

To estimate the environmental impacts from the production of diesel, the upstream production energy, which is the energy used in the production process, is calculated. The production process includes extraction of the raw oil, transporting the oil to the coast in Esbjerg, transportation on land to the refinery, refining the oil to diesel and the transportation to the consumers (Slentø et al. 2010).

The values of the environmental impact is estimated exclusive of the energy used for flaring[3], as the energy used for flaring is not productive and the level of production of North Sea oil is assessed not to be affected if an electric vehicle replaces a diesel vehicle. If the oil is not used for diesel fuel production to the Danish market it will either be exported or refined in another way.

The production of diesel results in emissions from the pollutants listed in figure 7.2.

Figure 7.2: Pollution from Production of Diesel

Emitted Pollutants	
CO_2 (Carbon dioxide)	CO (Carbon monoxide)
SO_2 (Sulphur dioxide)	HC (Hydrocarbon)
NO_x (Nitrogen oxide)	PM-Particles
CH_4 (Methane)	N_2O (Laughing gas)

Source: Slentø et al. (2010).

The size of the environmental impacts from the diesel combustion depends on the efficiency of the combustion. To make a complete combustion in the engine, every diesel particle needs to be combusted, which requires a sufficient amount of air (Dahl 2008 and Gyldendal 2011b). If the combustion is complete, the air and diesel is converted into carbon dioxide (CO_2), water (H_2O), nitrogen oxides (NOx) and sulfuric acid (H_2SO_4, which is created when SO_2 is emitted to the air). If the combustion is incomplete, the combustion will furthermore create carbon monoxide (CO), uncombusted fuel (HC) and soot particles (PM-particles). In newer diesel vehicles the most of the CO and HC is

[3] Flaring is the burning of excess oil and gas

removed from the exhaust by the use of a catalytic converter. In the figure below, are the emitted pollutants from driving the diesel vehicle listed.

Figure 7.3: Pollution from Driving

Emitted Pollutants	
CO2 (Carbon dioxide)	CO (Carbon monoxide)
SO2 (Sulphur dioxide)	HC (Hydrocarbon)
NOx (Nitrogen oxide)	PM-Particles

Source: Ministry of Transportation (2010) and Gyldendal (2011b)

The emitted pollution from the diesel vehicle is dependent on the kilometers driven. As the analysis is conducted in the current setting, developments in technology are not incorporated. This makes the yearly cost of pollution constant throughout life time of the vehicle.

7.1.5 Noise

When vehicles are driving, noise is emitted from the traffic, which induces a cost to society. The cost stems from the direct nuisance, which affects the house prices, and the indirect impact on health, where a high noise level can lead to stress, hypertension and cardiovascular diseases (Jakobsen et al. 2010). The problem is especially important in large cities where the concentration of traffic and population density is high (Copenhagen Economics 2008). The noise created from the conventional vehicle is created as wind-, motor-, tire- and exhausting noise.

The noise level can affect both the surroundings and the individual driver. If the noise level within the vehicle is above 70 DB, it is said to be tiring for the driver on long trips, and can therefore increase the possibility for traffic incidents (Grand 2002). At noise level is above 80 DB, an individual can get stress symptoms (Hauerslev 2005). If the level increases to 85 DB earmuffs should actually be used. The cost of noise is dependent on the noise level created by the vehicle and the noise level is considered to be constant throughout the life time of the vehicle.

7.1.6 Refueling Time

Refueling is a necessary condition for operating the diesel vehicle. The time used for refueling can be separated into two parts; the time used to drive to the refueling station and the time used to refuel the vehicle. As there are many refueling stations in Denmark, and they are placed along the main routes in all regions, it is assumed that the detour driven in order to drive to the refueling station is neglectable. The costs associated to the second part are measured as the time it takes to refuel the vehicle. The time used is considered a cost, since it could have been used alternatively as either leisure- or work time.

7.1.7 Marginal Excess Tax Burden

As identified in section 3.5, transfers to the government induce an additional cost to society, when the limiting effects on the overall tax collection, as a consequence of the political tax stop are not acknowledged. The additional cost is due to that the taxes create a suboptimal equilibrium by lowering the demanded quantity, which creates a dead weight loss (Boardman et al. 2006). The cost is evaluated as the marginal excess tax burden (METB), and will be assessed and monetized in section 8.1.7 with respect to the source of origin. The METB in the evaluation of a diesel vehicle stems from the investment cost, the operation cost and the maintenance cost, as the remaining cost are externalities, which has no tax effect.

7.2 The Electric Vehicle

The impacts in form of cost attached to the Renault Fluence is identified in the following subsections. The subsections will describe the costs that differ from the costs of the diesel vehicle in detail and discus the relevance of each of these costs.

7.2.1 Investment

As in the case of the diesel vehicle, the initial investment is the main cost associated with purchasing and operating the electric vehicle. The costs of the investment consist of three parts, the cost of the electric vehicle, the battery and the installation of a charge spot at home. Concerning the transfers to the government, there is no registration tax, as electric vehicles are exempted from registration tax, if the vehicle is registered before the end of 2012 (Ministry of Taxation 2011). At the moment there are political discussions about extending the period of exemption of the registration- and fuel consumption tax for the electric vehicle to 2015. However, it is not included in law at the present, why the tax exemptions only are applied in the analysis until ultimo 2012. Hence, for the investment in the electric vehicle the transfers to the government only consist of VAT.

In the solution from Better Place, the consumer leases the battery instead of purchasing it. The purchase of the battery is still a cost to society though, as Better Place has to import it from a foreign producer. When the consumer chooses to purchase the Renault Fluence, he or she is obliged to allow Better Place to install a charge spot near the home address. The investment cost is a onetime cost occurring in the beginning of the time period.

7.2.2 Operation

The "fuel" in the electric vehicle is electricity, and the operation costs are thereby mainly based on the cost of electricity. The electric engine works in the manner that electricity from the battery is converted into a rotating movement of the engine shaft. This movement is transferred to the wheels, which make the vehicle drive (Videnomenergi.dk 2011).

The price from Better Place does not reflect the true social cost to society, as the price besides the cost of electricity covers Better Place's overhead cost, profit and risk of introducing the solution. Instead, the cost of electricity to society is determined by the cost of producing and distributing the electricity. The price of electricity in Denmark is based on 13 different items. The description of the items capabilities is found in Appendix 7.

Besides the cost of electricity, the operation costs consist of a biannual fuel consumption tax, which is paid twice a year, and the yearly fee for road assistance.

7.2.3 Maintenance

The electric vehicle does not have a combustion engine and therefore does the vehicle not have any cost to e.g. motor oil or a particulate filter. Furthermore, it does not have as many technical components as the conventional diesel vehicle, as the engine only consists of four movable parts, where the conventional vehicle consists of many more (Better Place 2011e). Hence, there is less parts to maintain. Albeit the difference between the alternatives, the electric vehicle still have many parts that have to be repaired and maintained. The electric vehicle still has technical components, comforting parts and tires along with the few engine components (Danish Transport Authority 2010). As is the case with the diesel vehicle, the maintenance cost is depending on the kilometers driven and will occur over the life time of the vehicle.

7.2.4 Environmental Impact

To assess the environmental impact of operating the electric vehicle, the emitted pollutants must be evaluated. The electric engine do not pollute in itself, why the source of pollution is located in the production of the electricity. The pollution is thereby related to the amount of kilometers the vehicle is driving per kWh. The emitted pollutants from the production of electricity are listed in the figure below.

Figure 7.4: Pollution from Production of Electricity

Emitted Pollutants	
CO_2 (Carbon dioxide)	HC (Hydrocarbon)
SO_2 (Sulphur dioxide)	PM-Particles
NO_x (Nitrogen oxide)	CH_4 (Methane)
CO (Carbon monoxide)	N_2O (Laughing gas)

Source: Energinet.dk (2010b) and Ministry of Transportation (2010)

The CO_2 emissions created by combustion in the production depends entirely on the type of fuel used to produce electricity, while emission of SO_2, NO_x, CH_4, N_2O and PM-particles also depends on the technology used (Danish Energy Agency 2011c). The potential environmental improvements from year to year are based on the technology improvement on the power plants and the composition between the different sources of production (Energinet.dk 2010b). The emissions can be expected to decrease over time as a consequence of the higher share of RE-production of electricity such as wind energy. Hence, the technology and the source of electricity have a great impact on the society cost attached to pollution. As the development in technology improvements is uncertain and the economic evaluation is conducted within the current setting, the electricity mix of today is used.

7.2.5 Noise

The emission of noise from an electric vehicle is less than the noise from a conventional diesel vehicle at most speed levels (Copenhagen Economics 2008). This entails lower noise annoyance and thereby cost to society. The advantage of the electric vehicle is mainly that it creates less noise when accelerating and when driving at low speed levels.

The largest difference between the electric vehicle and the conventional diesel vehicle is thereby mainly when driving in the cities, where the noise annoyance is most significant. The reason behind the advantage in favor of the electric vehicle is that the noise created at low speed mainly is created from the engine. While with high speed the noise also comes from the tires. The electric vehicle does not have a combustion engine and therefore only creates noise when driving fast, which often is in the rural areas where the noise burden is less costly.

7.2.6 Switching Time

As discussed in section 7.1.6, the cost of time can be separated into two parts, the time used for driving to the switching station and the time used on switching the battery, respectively.

Especially the first part is important for the electric vehicle as it only has a range of 160 kilometers. This means that if it needs to drive more, it has to switch the used battery with a new one at a battery switching station or find a charge spot to get a quick- or a normal charge. This entails that if the individual, who drives the electric vehicle, knows that he or she never drives more than 160 kilometers per day the individual will have a flexibility increase because he or she never has to worry about finding a refueling opportunity. This is based on the argument that, with the charge spot installed at home, the vehicle will always be able to drive the wanted distance per day. Hence, it also implies that if the individual knows he or she often drives more than 160 kilometers per day, the individual would have to incorporate the switching opportunity in the planned route. As there are only 19 switching stations planned at the moment, the length of the detour in order to access a switching station will be a significant cost, because the individual will have to choose a route that is not the most direct and efficient. The cost of switching battery will be measured as the time it takes to drive to and from the switching station added the battery switching time.

7.2.7 Marginal Excess Tax Burden

The reasoning behind assessing the METB effects of the electric vehicle is similar to the reasons described in section 7.1.7. The METB associated to the electric vehicle also stems from the investment cost, the operation cost and the maintenance cost, as the remaining cost are externalities with no tax effects.

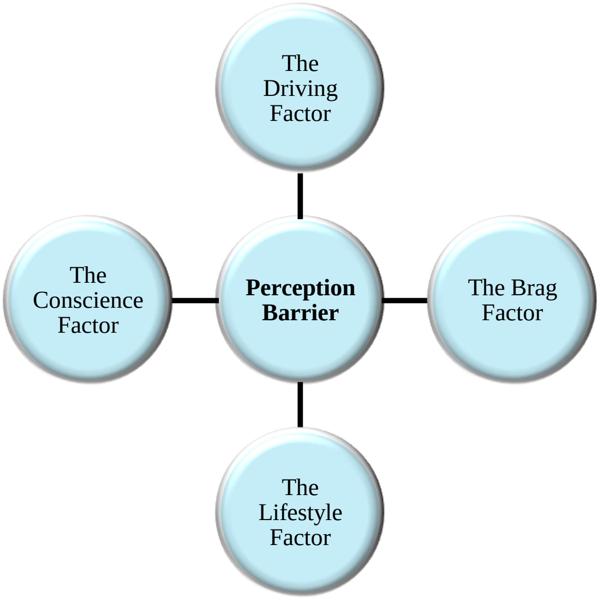
7.2.8 Perception Barrier

In the situation where an individual has to choose between purchasing an electric vehicle or a conventional diesel vehicle there may, in some cases, be a psychological barrier which influence the decision. The barrier can be assessed as a perception barrier, which implies that the individual not necessarily favors the alternative that has the lowest cost. The significance of the barrier depends on whether the underlying motive behind the purchase is pragmatic or emotional.

The perception barrier is individual, and it is defined according to the preferences of the individual that has to purchase the vehicle. It depends on which factor the individual assign most weight, and can both be in favor of the electric or the diesel vehicle. The perception barrier can be assessed in two dimensions; the personal level and the social level (Ulk et al. 2009). On the personal level, the vehicle is either seen as a tool for transportation or as an identity marker which functions as a mirror of the owner. On the social level the vehicle is either viewed as a practical solution in the everyday life or as a symbol of the owner's social status, where the vehicle functions as a means of transport, which is conducive for contact.

If the individual perceives the vehicle as tool for transportation on the personal level, it is likely that he or she also perceives it as a practical solution on the social level. In the same manner, the perceptions as an identity marker and as a social status symbol are linked. If the choice of vehicle is driven by the latter aspect there will be some factors that can induce an emotional perception barrier, as it is possible that the individual will act economically irrational. The emotional factors can overall be categorized into four groups which are illustrated below.

Figure 7.1: Factors of the Emotional Perception Barrier



Source: Own creation

The driving factor can both favor the electric and the conventional vehicle. In favor of the diesel vehicle, is if the individual likes high speed performance, then he or she might prefer the diesel vehicle due to the limited top speed of the electric vehicle. Likewise if the individual is afraid of running out of fuel he or she might choose the diesel vehicle. The latter can be a barrier in form of less flexibility or as a psychological reaction when driving, because the battery capacity meter falls quickly from full towards empty (Boxwell 2010). On the other hand, the driving factor can also be in favor of the electric vehicle. As the electric vehicle is very fast at low speed and has max performance from start, because it does not have any gears. This makes the electric vehicle a "fun" city-vehicle.

The brag factor can be viewed as a "man factor", where it perhaps is more masculine to have a fast, expensive and fancy vehicle compared to a slower and "greener" vehicle. If the purchase is affected by the brag factor, the individual enjoys being noticed and likes the envy from others.

In the lifestyle factor, the individual sees the purchase of the vehicle as a reflection of the person he or she is or would like to be. In the case of the electric vehicle the signaling value will e.g. be that the individual is acting greener and more responsible towards the globe and future generations. In this case, the price does not matter as much, because it is more the signaling value the vehicle sends to the surroundings that drives the purchase.

This leads to the last factor which is the conscience factor. If this factor drives the purchase, it is because the individual sees the electric vehicle as more environmentally friendly transportation method, and thereby a means to preserve the environment. This can have a value to the individual in two forms. Firstly, the individual can have an option value from the opportunity to use a cleaner environment in the future, and will therefore be willing to pay more for the environmental friendly vehicle. Secondly, the individual can have an existence value from the knowing of that other people and future generations can benefit from a cleaner environment, even though he or she never themselves will use it. In this light, the purchase is affected by an altruistic view on life.

Studies shows that the choice of vehicle normally involves a combination of feelings and reason, and thereby becomes an ideal-real compromise (Ulk et al. 2009). In the perfect world a contingent valuation analysis among the vehicle buyers, which investigates the stated and realized preference, should therefore be conducted. But due to limitations in this thesis, a quantification and monetization of the perception barrier will not be included. This means that there is a potential risk for a bias in the result of the analysis, because the potential psychological effect is being disregarded. The focus will be on the vehicle as a practical tool for transportation that covers the need for transportation from one location to another.

Even though the practical approach is chosen, the direction of the bias is important to discuss. At the moment, many people are not willing to act sustainable if it implies that they have to sacrifice present consumption possibilities or comfort. Furthermore, politicians often have a short sighted focus, as they have a wish of reelection. Albeit the lack of willingness, there are signs of new trends in society towards more thoughtfulness and less egoism. These signs can be seen among politicians and large corporations. The focus on the problems of the global environment have received large attention in the last years e.g. with the presence of the major politicians at the COP15 climate summit in Copenhagen in 2009, and almost all large corporations have implemented a Corporate Social Responsibility (CSR) strategy. This is all movements towards more willingness to make self-sacrifice for the benefit of others. But the politicians did not reach a solution at the summit, and the majority of the corporations have implemented the CSR strategies only with a philanthropic and/or risk minimizing purpose, because the underlying goal of the strategies is profit maximization. This leads to a perception bias that favors the diesel vehicle in the present. However, the increased focus from both politicians and corporations is like to reshape the private consumers' preference in the long run, and thereby make it actually beneficial for the politicians and corporations to act sustainable. This can drag the direction of the bias towards the favor of the electric vehicle in future.

8. Quantification and Monetization of Cost

The impacts identified in chapter 7, will in this chapter be quantified and monetized. The structure will be similar to the last chapter, meaning that the diesel vehicle will be examined before the electric vehicle.

8.1 The Diesel Vehicle

8.1.1 Investment

When purchasing a vehicle, an individual adjusts his consumption behavior to the market price. As the foundation of a CBA is the utility of the individuals in society, the accounting price of the vehicle is the market price (Ministry of Finance 1989 and Ministry of Finance 1999). In the case of the diesel vehicle the market price includes taxes and VAT, which is a transfer to the government. The Danish tax system regarding vehicles is divided into two different taxes – a registration tax and a fuel consumption tax. The registration tax is paid upon purchase of the vehicle and the fuel consumption tax is paid biannually (Ministry of Taxation 2010and Ministry of Taxation 2011). The structure of the registration tax will be presented below, and the structure of the fuel consumption tax will be discussed in section 8.1.2.

In registration tax, the buyer of the vehicle has to pay a tax of 105 percent on the first DKK 79,000 of the vehicle price incl. VAT, and pay a tax of 180 percent on the price that exceeds DKK 79,000 (Ministry of Taxation 2011). The tax foundation price is reduces, if the vehicle has certain predefined safety parts installed, such as ABS, ESP, safety test and radio. This is referred to as price deductible. For the Renault Megane the price deductibles amount to DKK 9,250. Furthermore, the overall registration tax is adjusted according to the fuel consumption of the vehicle and if particle filter, airbags and belt alarms are installed. This is referred to as tax deductible. For each kilometer the vehicle drives more than 18 kilometers per liter fuel, DKK 4,000 is deducted and contrary DKK 4,000 is added for each kilometer the vehicle drives less than 18 kilometers per liter fuel. The total tax deductibles amount to DKK 27,920.

The market price of the Renault Megane is the retail price of DKK 245,100 (Bilzonen.dk 2011). The transfer to the government is calculated as the price without taxes subtracted the retail price. The price without taxes is calculated by isolating P_{excl} in the equation for the market price derived from the law on registration tax (Ministry of Taxation 2011):

$$P_{incl} = (1 + VAT)P_{excl} + 79{,}000 \cdot 1.05 + \Big((1 + VAT)P_{excl} - deductible_{price} - 79{,}000\Big) \cdot 1.80 - deductible_{tax}$$

$$\Updownarrow$$

$$P_{excl} = \frac{\big(deductible_{price} \cdot 1.80 + deductible_{tax} + 79{,}000 \cdot (1.80 - 1.05) + P_{incl}\big)}{(1 + 1.80)(1 + VAT)}$$

Where P_{incl} is the market price and P_{excl} is the price without registration tax and VAT. Entering the market price in the equation and solving it, results in a price excl. tax of DKK 99,691.43, and thus a transfer to the government of DKK 145,408.57.

Table 8.1: Cost of Investment for Society, 2011 prices

	2012
Market Price	245,100.00
Transfer to the Government	145,408.57
Cost to society	99,691.43

Source: Bilzonen.dk (2011)

The cost to society of the vehicle is hence DKK 99,691.43.

In addition to the price of the vehicle are the costs associated with buying equipment in order to make the diesel and electric vehicles comparable. It was earlier identified that a purchase of an integrated navigation system was required. The market price of an integrated Carminat TomTom navigation system installed by Renault can be seen in table 8.2 below.

Table 8.2: Cost of Navigation system, 2011 prices

	2012
Navigation system	7,900.00
Transfer to the Government	1,580.00
Cost to society	6,320.00

Source: Renault (2011b)

Included in the cost of the navigation system is the transfer of VAT to the government. The cost to society of equipment is calculated below by deducting the transfer. Hence, the cost to society is DKK 6,320.00.

Combining the costs from above results in a total cost to society of the investment in the diesel vehicle of DKK 106,011.43.

8.1.2 Operation

As consumers are faced with market prices of diesel fuel, they adjust their driving behavior to the point, where the market price of diesel is equal to the marginal utility of diesel (Ministry of Finance 1989). Thus the market price of diesel should be used as the accounting price.

Several taxes are included in the market price of diesel. These are transfers to the government along with the biannual fuel consumption tax, and thus create a suboptimal consumption point for society. The diesel taxes consist of an energy tax, a NO_x tax and a CO_2 tax, while the biannual fuel consumption tax depends on the level of fuel consumption of the vehicle (Ministry of Taxation 2010).

According to the green book, the price of fuel will not follow the general inflation as the supply of resources is scarce (HM Treasury 2003). Thus, it is necessary to include the relative price increase, when accounting for the fuel price in the future time periods. The development in the market price of diesel from 1995 to 2011 is represented in Appendix 8. Here it is seen that the diesel price seems to have an increasing trend. The increase in the future fuel prices is incorporated in the forecast from the Ministry of Transportation (2010), why these prices are used.

In 2012 the market price of diesel is estimated to be DKK 9.93 per liter, which includes fuel taxes of DKK 4.95. The taxes are an energy tax, a NO_x tax, a CO_2 tax and VAT, and they are jointly approximately 100 percent of the fuel price without taxes. Hence, special care must be taken, when calculating METB in section 8.1.7.

Below in table 8.3 the calculation of cost to society per liter diesel is shown for 2012, and the cost to society for the full time period is shown in Appendix 9.

Table 8.3: Cost to Society per liter Diesel in 2012, DKK 2011 prices

	2012
Market Price	9.93
Government Transfers	
Energy tax	2.53
NOx tax	0.01
CO2 tax	0.42
VAT	1.99
= Total Transfers	4.95
Cost to Society	4.99

Source: Ministry of Transportation (2010)

In 2012, the cost to society of one liter diesel fuel is thus DKK 4.99.

In order to calculate the yearly cost of fuel, it is necessary to find the number of kilometers an average vehicle is driving per year. The calculation is based on the number of vehicles and the total number of person kilometers driven in Denmark in 2010. Afterwards this number is adjusted with the number of persons per vehicle.

Table 8.4: Calculation of average km driven per vehicle, 2010

	2010
Number of vehicles	2,071,698
Person km driven	51,785,000,000
Avr. person km per vehicle	24,996
Avr. persons per vehicle	1.39
Avr. km per vehicle	17,983

Source: Statistics Denmark (2011d), Ministry of Transportation (2010) and own calculations

This implies that a vehicle is driving 17983 km in average per year. The Renault Megane has, as described earlier, an average fuel consumption of 22.7 km/liter, which results in a fuel consumption of 792.2 liter diesel per year. When combining the yearly diesel consumption with the above cost per liter, it results in a cost to society of DKK 3,949.28 in 2012.

The biannual fuel consumption tax depends on the level of fuel consumption of the vehicle (Ministry of Taxation 2010). The tax levels can be seen in Appendix 10. The Renault Megane has a fuel consumption of 22.7 km/liter, which translates into a biannual tax of DKK 980. The total yearly transfer from the vehicle owner to the government is hence DKK 1,960. As this is exclusively a transfer, it is only examined in the METB calculation in section 8.1.7.

The cost of the roadside assistance is obtained as the market price from Danish Roadside Assistance (Dansk Autohjælp). The yearly market price is DKK 659, which includes a transfer of DKK 131.80 in VAT (Dah.dk 2011). Hence, the cost to society of roadside assistance is DKK 527.20

The above estimates yield a cost to society for operating the diesel vehicle of DKK 4,476.48 in 2012.

8.1.3 Maintenance

The cost of maintenance is calculated on basis of kilometers driven (Ministry of Transportation 2010). As discussed earlier, the average vehicle drives 17983 km per year. The cost to society consists of the market prices per kilometers deducted the transfer to the government in form of taxes.

The cost associated with the maintenance of the conventional diesel vehicle can, as mentioned, be separated into three parts, which are presented below in table 8.5.

Table 8.5: Maintenance cost per kilometer, in DKK 2011 prices

	Excl. tax	Incl. tax
Motor oil	0.022	0.028
Tire	0.035	0.043
Reparation & Maintenance	0.357	0.457

Source: Ministry of Transportation (2010)

The estimates of the three parts of maintenance cost give a total maintenance cost of DKK 0.528 and a transfer of DKK per 0.114 kilometer driven. The maintenance cost for the conventional diesel vehicle to society is hence 0.414 DKK per kilometer. The cost is constant over the life time of the vehicle because it is not a scarce resource and thereby only follows the inflation. Given the average yearly driving of 17,983 kilometers, the total yearly cost is DKK 7,440.07.

8.1.4 Environmental Impact

As discussed in the identification of costs section, the environmental impacts from the conventional diesel vehicle comes from two sources – the production process and the combustion of diesel when driving.

The source of emission sizes from production is based on research from the National Environmental Research Institute (DMU), wherein both the direct emissions from production and the use of energy in the production process are investigated. The costs of pollution values are obtained from the Ministry of Transportation (2010) as a weighted average of the cost of polluting in urban and rural areas.

Table 8.6: Pollution from Production of Diesel in Denmark 2007, DKK 2011 prices

Emissions to air	g/MJ	g/liter	g/km	CO2 eq.	DKK/g	DKK/km
CO2 (Carbon dioxide)	79.4000	2847.92	125.4590		0.000129	0.016197
SO2 (Sulphur dioxide)	0.0100	0.3587	0.0158		0.201605	0.003186
NOx (Nitrogen oxid)	0.7560	27.1162	1.1945		0.048388	0.057802
CO (Carbon monoxide)	0.1510	5.4161	0.2386		0.000014	0.000003
HC (Hydrocarbon)	0.0350	1.2554	0.0553		0.002416	0.000134
PM-Particles	0.0190	0.6815	0.0300		0.775886	0.023293
CH4 (Methane)	0.0150	0.5380	0.0237	0.4977	0.000129	0.000064
N2O (Laughing gas)	0.0030	0.1076	0.0047	1.4695	0.000129	0.000190
Pollution Cost from Production						**0.1009**

Note: Based on energy content of 42.7 MJ/kg, diesel density of 0.84 kg/liter and fuel consumption of 22.7 km/liter.
Source: Slentø et al. (2010), Ministry of Transportation (2010)

As it appears from table 8.6, the pollution from the production process of diesel has a cost of DKK 0.1009 per kilometer driven. The main contributor to the pollution cost is the emission of NOx, which represents more than half of the cost. Besides the emission of NOx, emissions of CO2 and PM-particles have the largest role in the cost of pollution.

The emission from driving is based on official numbers from Renault and estimates from the website www.car-emissions.com. The cost of pollution from driving the Renault Megane can be seen below.

Table 8.7: Pollution from Driving, in 2011 prices

Emissions to air	g/km	CO2 eq.	DKK/g	DKK/km
CO2 (Carbon dioxide)	115		0.00013	0.0148
SO2 (Sulphur dioxide)	0.005		0.20160	0.0010
NOx (Nitrogen oxide)	0.162		0.04839	0.0078
CO (Carbon monoxide)	0.413		0.00001	0.0000
HC (Hydrocarbon)	0.38		0.00242	0.0009
PM-Particles	0.029		0.77589	0.0225
CH4 (Methane)	-	-	0.00013	-
N2O (Laughing gas)	-	-	0.00013	-
Pollution Cost from driving				**0.0471**

Source: Renault (2011a), Car-emissions.com (2011), Ministry of Transportation (2010) and own calculations.

As can be seen in table 8.7 above, the pollution cost of driving is DKK 0.0471 per kilometer. Together with the pollution cost associated to the production, it yields a total cost of pollution of DKK 0.1480 per kilometer driven. With an average yearly driving distance of 17,983 kilometers, the yearly environmental cost to society is DKK 2,661.25.

8.1.5 Noise

The overall cost of noise to society consists of nuisance- and health cost (Ministry of Transportation 2004). The nuisance cost reflects how bothersome the noise is experienced and is measured as the willingness to pay in order to avoid the noise annoyance (Ministry of Transportation 2010). The health cost is attached to the indirect diseases the noise can endow, and is measured from the cost to society of sickness and early death (Jakobsen et al. 2010 and Ministry of Transportation 2010). The cost of noise is highly dependent on the specific local surroundings, such as population density, time of the day, vehicle type, speed levels etc. (Ministry of Transportation 2004).

The marginal cost of noise for an extra kilometer driven is estimated based on the change in the overall noise level caused by a change in the traffic quantity (Copenhagen Economics 2008). In practice this is done by simulating the traffic changes, and afterwards calculating the cost per extra kilometer driven. The simulation has been conducted for different cities in Denmark to obtain measures that reflect the differences in surroundings.

Due to the high dependency of the surroundings, Copenhagen Ecomics (2008) uses three different cost levels depending on whether it is in Copenhagen, urban areas with above 20,000 inhabitants or rural areas. Because of the population density and the traffic patterns Copenhagen is weighted 40 percent, urban areas 40 percent and rural areas 20 percent. Based on the approach described above and the weights, the costs of noise for the different areas are estimated to be:

Table 8.8: Cost of Noise for the diesel vehicle, in DKK 2011 prices

	Kilometers	DKK/km	Cost of Noise
Copenhagen	7,193	0.403	2,895.69
Urban	7,193	0.314	2,262.26
Rural	3,597	0.013	45.25
Total	17,983		5,203.20

Source: Copenhagen Economics (2008) and own calculation

Based on the above, the cost of noise to society of driving the diesel vehicle is estimated to DKK 5,203.20 per year.

In order to assess the reliability of this cost, it is compared to a rough estimated from 2000. Here, the overall cost of noise to society for person vehicles was estimated to be DKK 6.5 billion in 2000 prices (Copenhagen Economics 2008). With a corresponding vehicle fleet of 1,843,254 vehicles (Statistics Denmark 2011d), this entails a cost per vehicle of DKK 4436 in 2011 prices. The estimated yearly cost of noise is higher, but as the traffic patterns and population distribution might have changed, it seems to be a reasonable estimate.

8.1.6 Refueling Time

Not all commodities and services are traded in a market and thereby can be assessed by the market prices. Goods like time, accident frequency etc. should therefore be assessed as the marginal utility of the goods and thereby willingness-to-pay (Ministry of Finance, 1989). Hence, if there is a time saving in the project under evaluation, the required compensating variation is equal to the largest sum the individual is willing to pay in order to get the amount of saved time (Mishan & Quah 2007).

The value of time varies according to the context, in which it is used. The price depends, according to Mishan and Quah (2007) on the individual person whom achieves it, and should therefore in theory be assessed according to the individual's preferences. Furthermore, the value of the time spend varies according to the purpose of use. The different forms of use can be distinguished in either working- or leisure time (Tipping 1968). Working time represents use of labor and thereby use of a production factor. If the time would have been the used as working time, the valuation should be based on the hourly wage from the society's point of view (Ministry of Finance 1989). In order to obtain an appropriate price, which reflects the welfare of the individuals in the society, the factor prices of wage are converted into market prices by the use of the net tax factor (Ministry of Transportation 2010).

If the time is not used for working, it should be assessed as leisure time, which is measured as a benefit for the individual person (Tipping 1968). The leisure time is a consumer good and is valued as the individual willingness-to-pay for the amount of time. The value of the leisure time cannot exceed the value of working time, since the individual therefore always would choose to work less (Ministry of Finance 1989).

Besides the alternative use of time, the cost of time depends on the possibility of planning the time. This is the concept of travel time reliability, which according to Bhat and Sardesei (2006) can be assessed in two different ways. Either the individual cannot control the time due to e.g. traffic congestions, which can lead to stress and anxiety, or the individual have the possibility to control the time, e.g. when dropping of children, refueling or switching batteries. Hence, the time associated with refueling is considered as time the individual can control.

As discussed in section 7.1.6, there are no costs attached to the time it takes to drive to the station, as the refueling stations are widely distributed across Denmark, and therefore it will not significantly impact the route the individual is driving. The prices of time are obtained from the Ministry of Transportation (2010), which has based the values on research in "The Danish Value of Time Study" from 2007. The prices can be seen in table 8.9 below.

Table 8.9: Cost of Time in DKK per minute, 2011 prices

	Work time	Leisure time
Drive time	5.55	1.31
Congestion	8.32	1.96

Source: Own calculation based on Ministry of Transportation 2010

In the assessment of the value of time, it is important to state that only amounts of time that have a significant impact on the society should be counted as working time (Mishan and Quah 2007). A saving of ten minutes is unlikely to be used for extra work and should be assessed as leisure time, while a saving of 30 minutes is more likely to be used for extra work (Tipping 1968). In the calculation of the time cost of refueling, the time will be regarded as leisure time, if the total time is under 30 minutes and as work time if the total time is above 30 minutes per refueling. The price of time is furthermore weighted according to how many people that are expected to be in the vehicle, which is based on the Ministry of Transportation's estimate of the occupancy rate to be 1.39 persons per vehicle.

To assess the amount of time an average vehicle uses to refuel the vehicle each year, the expected number of refueling is calculated. It was described in section 5.1 that the Renault Megane has a fuel tank capacity of 60 liters and can drive 22.7 kilometers/liter. It is assumed that the refueling is conducted when ¾ of the tank capacity is used, and the vehicle is fully refueled every time. This entails that the distance driven per refueling is 1,021.5 kilometers, which implies that an average vehicle will have to refuel 17.6 times per year, when driving 17,983 kilometers.

In order to estimate a reliable measure of the time used on refueling, a field study has been conducted. The purpose of the field study was to obtain a sample of refueling times. The locations were selected to be four different refueling stations in Aarhus, which was observed at different times of the day – in morning, around noon and in the afternoon. Two of these stations had a shop in connection with the refueling station. The refueling time is defined as the time from the vehicle crosses the pavement into the refueling station area, until it crosses the pavement out of the refueling station area. In total, the sample includes 87 observations. The characteristics of the sample are presented in table 8.10:

Table 8.10: Descriptive statistics of refueling time sample

	Seconds	Minutes
Average time	228.74	3.81
Standard Deviation	92.35	1.54
Median	214	3.57
Skewness	1.13	1.13

Source: Field study – the authors' own observation.

Based on the sample described in table 8.10, the mean refueling time is estimated to be 228.74 seconds or 3.81 minutes, which results in that the time is evaluated as leisure time.

Combining the above, the yearly cost attached to the time used on refueling the diesel vehicle is calculated to be DKK 121.78.

8.1.7 Marginal Excess Tax Burden

The quantification and monetization of METB will be based on the theory discussed in section 3.5. The rate of METB depends on the size of the tax, which creates the dead weight loss. For transfers created by VAT and lower tax levels, the recommendation from the Ministry of Finance (1999), which is a rate of 20 percent, will be applied. In the cases, where the transfers are generated from a significantly higher tax rate and the price elasticity of demand is available, the methodology of Møller and Jenesn (2004) will be applied.

Concerning the investment, METB occurs from two sources – the purchase of the vehicle and the purchase of the navigation system. In order to be able to calculate the dead weight loss from the registration tax and VAT of the vehicle, the components of the calculation recommended by Møller and Jenesn (2004); the tax percentage, the price exclusive tax, the demanded quantity and the price elasticity of demand are discussed below.

The tax percentage is calculated to be 145.86 percent based on a market price of DKK 245,100 and the structure of the Danish tax system described in section 8.1.2, where the price excl. tax was calculated to be DKK 99,691.43. The quantity of newly registered person vehicle was 153,611 in 2010 (Statistics Denmark 2011e).

In the determination of the price elasticity of demand for vehicles, it is necessary to distinguish between short run and long run elasticity. As stated earlier, a vehicle is a durable good. If the price increases, the purchase of a durable good is likely to be postponed to a future period (Pindyck and Rubinfeld 2005). In the long run consumers will need to replace their vehicle as the old vehicles are worn down, implying that the price increase will have the largest effect on demand in the short run. Thus the demand is less elastic in the long run. In the analysis of the implications of changes in the structure of vehicle taxes, the Danish Environmental Protection Agency (2007) operates with a long run price elasticity of demand for vehicles in Denmark of -0.57.

Combining the above estimates yields the following cost in form of a dead weight loss from the taxation of the vehicles:

$$METB = \frac{1}{2} \cdot 1.4586^2 \cdot \frac{99{,}691.43 \cdot 153{,}611}{1/_{(-0.57)}} = 9{,}285{,}159{,}584.92$$

Thus, the dead weight loss for the vehicle fleet is DKK 9,285,159,584.92, which translates to a dead weight loss per vehicle of DKK 60,445.93.

When applying the METB rate of 20 percent in the calculation of METB due to VAT on the navigation system, it results in a dead weight loss of DKK 316.00.

In the calculation of METB from the diesel fuel taxes, the recommendation by the Ministry of Finance is not appropriate, as the tax rate is 99.2 percent of the fuel price without taxes, which is expected to be DKK 4.99 in 2012. Hence, the computation suggested by Møller and Jensen (2004) is used.

The long run price elasticity of demand of auto fuel is estimated to be -0.7 by Johansson and Schipper (1997). The quantity of consumed diesel fuel was 3,485,834,000 liters in 2010 (Danish Petroleum Association 2011a)

Entering this in the equation for calculating METB yields a cost to society from the total diesel fuel demand of DKK 5,988,388,338.93 in 2012

$$METB = \frac{1}{2} \cdot 0.992^2 \cdot \frac{4{,}99 \cdot 3{,}485{,}834{,}000}{1/_{(-0.7)}} = 5{,}988{,}388{,}338.93$$

This translates to a cost of DKK 1.72 per liter diesel fuel. With a yearly consumption of 792.20 liter diesel for the vehicle, this results in a cost of DKK 1,360.94.

In the case of the fuel consumption tax, the METB recommendation from the Ministry of Finance (1999) of 0.2 is used to calculate the dead weight loss from the transfer, because tax rate is relatively small compared to the yearly operating cost. Thus, with a yearly fuel consumption tax of 1,960, the cost to society from METB of the fuel consumption tax is DKK 520 each year

The VAT on the roadside assistance results in a METB of DKK 26.36 each year, while the VAT on maintenance cost results in a METB of DKK 410.49 each year.

In total this yields a cost to society of METB of DKK 62,951.72 in 2012. In 2013 the cost of METB is DKK 2176.19 due to the absence of the initial investment.

Having quantified and monetized the relevant costs for the diesel vehicle, the following section will apply the same procedure for the electric vehicle.

8.2 The Electric Vehicle

8.2.1 Investment

As discussed in section 7.2.1, the cost to society of the investment is the cost of the vehicle, the battery and the installation of a charge spot.

The cost to society of the investment is measured similar to the method for the diesel vehicle. The market price of the Renault Fluence is DKK 205,000 (Renault 2011c). As there is no registration tax on electric vehicles registered before ultimo 2012, the transfer to the government only consists of VAT. This leads to a cost to society of the vehicle of DKK 164,000.00, as can be seen in the table below.

Table 8.11: Cost of Investment for Society, 2011 prices

Cost of Vehicle	2012
Market Price	205,000.00
Transfer	41,000.00
Cost to society	164,000.00

Source: Renault (2011c)

To estimate the cost of the battery, price information of a similar battery from a Nissan Leaf is used. The battery is from the same supplier, ASEC, which is owned by Nissan and Renault in cooperation. The lithium-ion battery installed in the Renault Fluence is a 24 kWh battery, which is in accordance with the battery in the Nissan Leaf. According to Nissan Executive Andy Palmer, the production cost of the battery is USD 9,000 (Arlidge 2010). The exchange rate between DKK and USD was 5.1832 DKK/USD on the 1st of June (Valutakurser.dk 2011), which yields a production cost of the battery of DKK 46,684.80. As the battery is imported, the purchase creates a currency expenditure, which leads to a foreign claim on society. As discussed in section 3.4, the Ministry of Finance (1999) recommends using an accounting price, which is the import price multiplied with the NTF. The transfer is assessed as the VAT calculated in accordance to the import price and is subtracted from the accounting price to obtain the cost to society.

Table 8.12: Cost of the Battery for Society, in 2011 prices

Cost of Battery	**2012**
Import Price	46,648.80
Accounting Price	55,045.58
Transfer	11,662.2
Cost to society	43,383.38

Source: Arlidge (2010), Valutakurser.dk (2011) and Statistics Denmark (2011c)

This gives a cost to society of DKK 43,383.38 for the battery in 2012, as can be seen in the table above.

When purchasing a Renault Fluence, it is a prerequisite also to purchase a charge spot from Better Place. The Market price of the charge spot is DKK 9,995, which includes VAT of DKK 1,999 (Better Place 2011f). Furthermore, the installation requires a connection fee to the local net company, which varies according to the geographic location (Better Place 2011c). The range of the connection fee is DKK 0 to 10,000. As discussed earlier, the connection fee is set to DKK 2,000. In the table below the cost to society is calculated.

Table 8.13: Cost of the Charge Spot for Society, in 2011 prices

Cost of Charge Spot	2012
Market Price	11,995.00
Transfer	2,399.00
Cost to society	9,596.00

Source: Better Place (2011c) and Better Place (2011f)

This gives a cost to society of DKK 9,596 for the installation of the charge spot in 2012.

In total the cost of the vehicle, the battery and the charge spot yields a cost to society of DKK 216,979.40 in 2012.

8.2.2 Operation

The operation cost of Renault Fluence consists of the cost of electricity, fuel consumption tax and road assistance.

The cost of electricity to society is determined by the cost of producing and distributing the electricity, as discussed in section 7.2.2. Besides this cost, it can be argued that an additional cost should be included, as Better Place is the sole provider of the battery leasing solution, and thus can be assessed as a monopoly. The monopoly situation enables Better Place to behave inefficient for society, as it is possible to charge a price higher than the perfect competition price. This would entail a dead weight loss to society. Albeit, it is theoretical possible for Better Place to earn monopoly profit, the company has high initialization cost in form of e.g. battery switching stations and investment in batteries. Furthermore, the amount of electric vehicles operated by Better Place is expected to be rather low in the beginning. Thus, within he life time of the vehicles it is assessed that Better Place will not be able to earn supernormal profit, why the possible dead weight loss from a monopoly pricing strategy is excluded in the analysis.

The cost of electricity is measured as the market price deducted transfers and sunk cost (Danish Energy Agency 2011c). In the following section the composition of the electricity price will be discussed, and the separate items will be classified. The electricity price can be divided into 13 items (Danish Energy Association 2011). These items can be subcategorized into three different groups; Government Transfer, Sunk Cost and Producer Fee (Danish Energy Agency 2011c) which is illustrated in table 8.14.

Table 8.14: Categorization of the Items in the Electricity Price

	Goverment Transfer	Sunk Cost	Producer Fee
Items in the Electricity Price	Electricity tax + extra charge Electricity distribution tax Electricity savings contribution Energy savings tax VAT PSO	Reg. Transmission Net tariff Subscription Subscription (net)	Net tariff local System tariff Commercial price
DKK/kWh	**1.305**	**0.246**	**0.643**

Source: Danish Energy Association (2011) and Danish Energy Agency (2011c).

As can be seen in table 8.14, six of the thirteen items in the electricity price are transfers. These transfers are collected taxes to the government and the PSO, which is a subsidy to sustainable energy development paid by the producer to the government. The transfers are deducted from the market price in order to obtain the cost to society. The implications from the dead weight loss due to the transfers are examined in section 8.2.7.

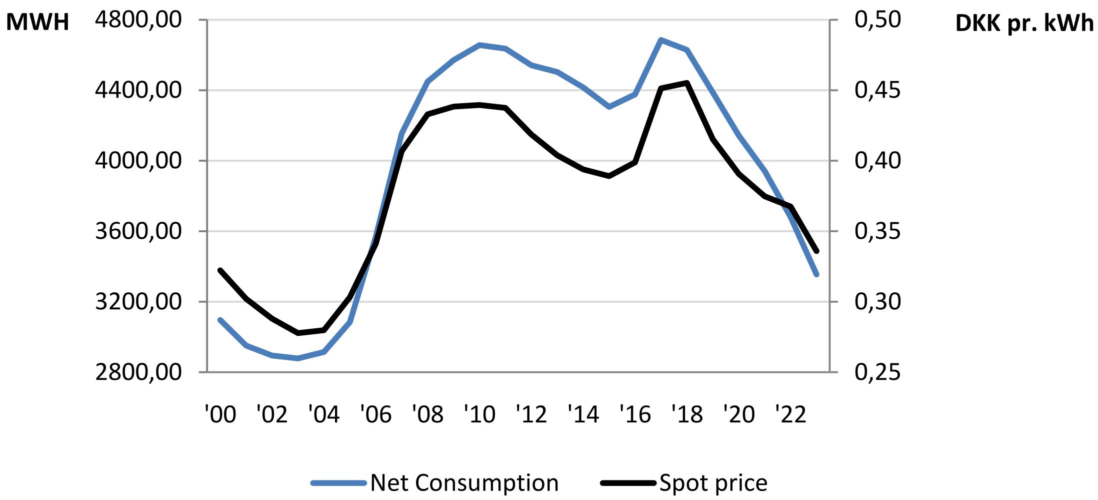
One of the important aspects, in the assessment of the society's electricity price, is to separate the transportation of electricity. The transportation both covers the transmission net and the distribution net, but these should be assessed differently (Danish Energy Association 2010a). The regional transmission covers the transportation of electricity from the producer to the local net-company and the net tariff covers the cost of maintaining the Danish transmission net (400-132 kV). These are, together with the subscriptions cost, assessed as sunk cost because they are seen as depreciations on the net (Danish Energy Agency 2009). The cost is assessed as sunk cost because they are unaffected by the size of the present consumption and thereby not depend on fluctuations in the consumption ((Danish Energy Agency 2011c). The sunk cost should not be included in a CBA because there is no opportunity cost involved and they are therefore irrelevant (Boardman et al 2006).

The fee to the producer consists of three items, which is discussed in the following. The net tariff local is the cost attached to the local net-company for transporting and distributing the electricity to the consumer's home. The system tariff covers the cost to keep reserve capacity and system operations. The commercial price of electricity is the liberalized fixed quarterly price the universal service obligation companies ("forsy-

ningspligtige virksomheder" in Danish) charge the consumers. The price has to be approved by energy supervisory in Denmark and consists of the spot price on the Nord Pool market and the universal service obligation companies' profit margin. Thus, the commercial price does not illustrate the true price for the society, because it both consist of a non-weighted average spot price and a profit margin for the electricity company, which basically is a transfer from one individual to another.
From the above elaborations of the items, it is seen that the cost of electricity to society consist of the spot price, the distribution fee in terms of the net tariff local and the operation fee in terms of the system tariff.

The spot price of electricity depends upon the proportion between supply and demand; hence, it differs depending upon the hourly consumption of electricity, and in which part of Denmark the electricity is produced. In the table below the price- and consumption level can be seen during the day.

Figure 8.1: The Average Hourly Spot Price of Electricity and Consumption in 2010



Source: Energinet.dk (2011a) and own calculations

As aligned in the figure above the spot price of electricity is lowest during the night time and peaks in the morning and dinner hours. Furthermore, a high correlation between the net consumption and the spot price is seen. The net consumption is the consumption minus the transmission loss; hence, it is the consumption of electricity the consumer actually consumes without the transportation loss in the transmission net (Energinet.dk 2011b).

In order to find a cost of electricity to society, which reflects the fluctuating consumption, a weighted average of the spot prices during the day is calculated with net consumption as weights. The weighted average spot price is estimated based on hourly data from 2010 extracted from Energinet.dk (2011a), and the price is extrapolated each year until 2024 based on the expected changes in the price electricity from the Ministry of Transportation (2010). Below is the calculation of the cost of electricity shown for 2012.

Table 8.15: Cost of electricity per kWh, in DKK 2011 prices

	2012
Spot Price	0.4125
Distribution & Operation Fee	0.1819
Cost of Electricity	0.5945

Source: Energinet.dk (2011a), Ministry of Transportation 2010 and own calculations

Based on the consumption weighted spot price the cost of electricity to society is DKK 0.5945 per kWh in 2012. If the precise user profile was known, and thereby information of exactly when the batteries are recharged, it would be possible to conduct a more precise calculation.

As described earlier, the electric vehicle uses 225 watt per kilometer driven, which translates into 4.44 kilometers per kWh (FDM 2011c). A yearly driving of 17,983 kilometers will thus result in a usage of 4,046.18 kWh per year. Hence, the cost of electricity is DKK 2,405.31 in 2012. In Appendix 11 is the society cost of electricity illustrated from 2012 to 2024.

Besides the electricity costs the operation costs consist of a biannual fuel consumption tax. The tax depends on the level of fuel consumption of the vehicle (Ministry of Taxation 2010). According to the law on fuel consumption tax, §1 section 3, electric vehicles are exempted from the fuel consumption tax until ultimo 2012. As the electric vehicle uses no fuel, the "fuel" consumption will be calculated based on the weight of the vehicle from 2013 and onwards. Based on the Ministry of Taxation (2010), the formula is derived to be:

$$"\text{Fuel } consumption" = \frac{100}{3 + (0.5\% \cdot weight)}$$

With a weight of 1600 kg this entails a “fuel consumption” of 9.09 km per liter. The tax of the electric vehicle is determined by the tax level from a petrol vehicle, which can be seen in Appendix 12, and it results in a biannual tax of DKK 3,750. As this is a transfer to the government, it only has implication for society in form of a resulting dead weight loss, which will be assessed in section 8.2.8.

Lastly, the cost associated with roadside assistance is similar to the case of the diesel vehicle. The yearly market price is DKK 659.00, including DKK 131.80 in VAT. Hence, the cost to society of roadside assistance is DKK 527.20.

Combining the estimates above, the total operation cost to society of driving the electric vehicle is DKK 2,932.51 in 2012.

8.2.3 Maintenance

As discussed in section 7.2.3, the electric vehicle has fewer moveable parts than the diesel vehicle. This naturally implies that the cost associated with reparation and maintenance can be expected to be less than the cost of the conventional diesel vehicle. According to Better Place (2011g) the electric vehicle has, in the current setting, a maintenance cost that is 75 percent of the cost of the diesel vehicle. As the electric vehicle is expected to be in mass-production in 2015, the future cost is expected to be 50 percent of the cost of the conventional vehicle when driving 20000 km per year (Danish Transport Authority 2010). The maintenance cost to society consists of the market prices per kilometers deducted the tax transfer to the government.

The cost is illustrated as DKK per kilometers driven as 75 percent and 50 percent of cost to the diesel vehicle and can be seen in the table 8.16 below.

Table 8.16: Maintenance Cost per kilometer in 2012 and 2015, DKK 2011 prices

	2012	**2015**
Maintenance Cost	0.396	0.264
Transfer	0.086	0.057
Cost to Society	0.310	0.207

Source: Ministry of Transportation (2010), Better Place (2011g) and Danish Transport Authority (2010)

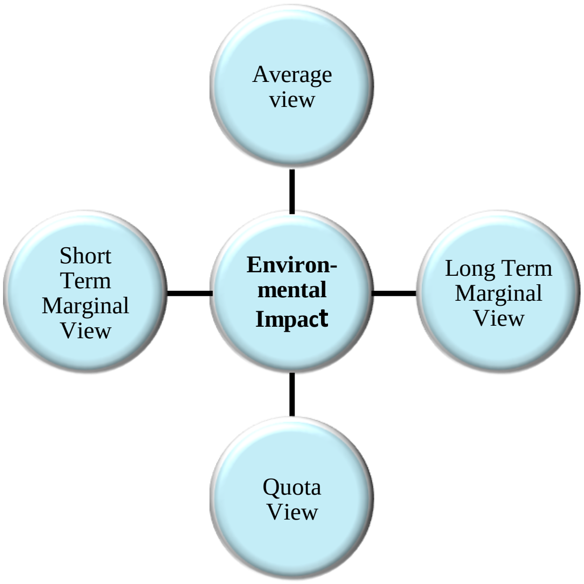
From the above it can be seen that the cost to society per kilometer driven is DKK 0.310 from 2012 to 2014, and DKK 0.207 from 2015 an onwards. This implies that the total yearly cost, when driving 17,983 kilometer in the electric vehicle, is DKK 5,580.05 and DKK 3,720.03 respectively.

8.2.4 Environmental Impact

In order to estimate the environmental impact of the electric vehicle, the environmental electricity declaration is investigated. In Denmark the declaration is separated into West and East Denmark (Energinet.dk 2010b). The reason for this is that there are no electric connections over the Great Belt. Therefore, the composition of energy sources used in production differs between West and East Denmark. The composition of the electricity production can be seen in Appendix 13.

According to Danish Energy Agency (2010b), there are four different approaches to assess the environmental impact on society from production of electricity, which is shown in the figure below.

Figure 8.2: Approaches to cost of pollution



Source: Danish Energy Agency (2010b)

The emissions emitted from producing one kWh can be assessed by the four approaches, and the choice of approach depends on the context in which the evaluation is conducted. Unfortunately the result differs depending on the choice of approach, thereby there is attached some uncertainty to the results (Danish Energy Agency 2010b). Below is the four approaches described.

The average view is based on what an average kWh in Denmark is emitting of pollutants corresponding to the weighted average production of electricity.
The quota view is based on the CO_2-quota system, implying that when there is emitted more CO_2 somewhere in the society then is there emitted less elsewhere. This results in that the total emission level does not increase. This implies that an introduction of an electric vehicle in principle would lead to an increase of zero emissions.
The long term marginal view is based on an assessment of the emission from the electricity source today compared to the energy source in the future. This implies that if the future electricity source is more renewable energy, the emissions of producing more electricity would be lower in the future.
The short term marginal view is based on how an extra unit of electricity would be produced in the present. Hence, the extra production has to be created based on the condition in the market right now. This implies that the production would be based on power plant production, because power plants are used to meet the fluctuating demand through the power regulation market. This would lead to a higher emission level.

As the electricity consumption profile of the user is unknown and the expansion of electric vehicles is assumed not to impact secondary markets, the approach is chosen to be the average view. This implies that the economic evaluation is conducted based on a weighted average of production in West and East Denmark to estimate a general cost of pollution from electricity production.
In Appendix 14, the emission levels are illustrated based on the long and short term marginal views, which is used in the sensitivity analysis. This is assessed to be equivalent to that the source of electricity is only fossil power plant fuel or only wind energy.

The declaration of the electricity can be seen below, which shows the different amounts, in g/kWh, of the pollutants that are emitted in the production of electricity in East and West Denmark.

Table 8.17: Emissions to air in g/kWh Environmental Electricity Declaration in 2009

	West-Denmark	East-Denmark	Average Electricity
CO_2 (Carbon dioxide)	438	460	445.411
SO_2 (Sulphur dioxide)	0.05	0.14	0.080
NO_x (Nitrogen oxid)	0.33	0.42	0.360
CO (Carbon monoxide)	0.12	0.16	0.133
HC (Hydrocarbon)	0.05	0.03	0.043
PM-Particles	0.02	0.01	0.017
CH_4 (Methane)	0.25	0.14	0.213
N_2O (Laughing gas)	0.005	0.008	0.006
Weight	66%	34%	

Source: own calculations based on (Energinet.dk 2010b).

The environmental declaration is based on a 125 percent heat efficiency, which is reflecting the effectiveness in the decomposition from fuel to heat (Energinet.dk 2010b). Based on table 8.17 it can be seen that the pollutants with the largest impact on the environment, after CO_2, are NO_x and CH_4 . It is specially nitrogen that is dangerous for humans because it can cause asthma, allergies and in some cases cancer and heart diseases (Dahl 2008). Methane is also very important since it provides 20 percent of the total greenhouse gas emissions (Danish Energy Agency 2011d). In table 8.18 the cost attached to emitting the different pollutants is calculated per kilometer driven.

Table 8.18: The Price of Pollution from Production of Electricity

Emissions to air	**g/kWh**	**CO2 eq.**	**DKK/g**	**DKK/kWh**	**DKK/km**
CO_2 (Carbon dioxide)	445.411		0.00013	0.0575	0.0129
SO_2 (Sulphur dioxide)	0.080		0.20160	0.0162	0.0036
NO_x (Nitrogen oxid)	0.360		0.04839	0.0174	0.0039
CO (Carbon monoxide)	0.133		0.00001	0.0000	0.0000
HC (Hydrocarbon)	0.043		0.00242	0.0001	0.0000
PM-Particles	0.017		0.77589	0.0129	0.0029
CH_4 (Methane)	0.213	4.472	0.00013	0.0006	0.0001
N_2O (Laughing gas)	0.006	1.863	0.00013	0.0002	0.0001
Pollution Price				**0.1050**	**0.0236**

Source: Ministry of Transportation (2010), Energinet.dk (2010b) and own calculations

The emission from the production is reported in g/kWh. Both CH_4 and N_2O are greenhouse gasses and are therefore calculated as CO_2-equivalents by multiplying CH_4 with 310 and N_2O with 21 (Danish Energy Agency 2011c). The price of polluting is reported as DKK/g where the price is a weighted average of land and city. Afterwards the price per kWh and kilometers is calculated. The calculations are based on that the electric vehicle under evaluation is driving 4.44 km per kWh. Hence, the cost of polluting for the society is DKK 0.1050 per kWh and thereby DKK 0.0236 per km driven in the electric vehicle. This results in a yearly cost of pollution to society from the electric of DKK 424.68.

8.2.5 Noise

The estimation of the cost of noise for the electric vehicle is based on the same approach as for the diesel vehicle. The only component which is changed is the price of noise per kilometer. The change in cost of noise is only present in Copenhagen and urban areas, because the electric vehicle has a noise advantage when accelerating and at low speed levels. The costs of noise to society for the different areas are estimated to be:

Table 8.19: Cost of Noise for the electric vehicle, in DKK 2011 prices

	Kilometers	DKK/km	Cost of Noise
Copenhagen	7,193	0.075	542.94
Urban	7,193	0.138	995.39
Rural	3,597	0.013	45.25
Total	17,983		1,583.58

Source: Copenhagen Economics (2008) and Ministry of Transportation (2010)

As it can be seen in the table above, the yearly cost of noise to society is estimated to be DKK 1,583.58.

8.2.6 Switching Time

As discussed in section 8.1.6, the cost of time is depending on whether the time alternatively would have been used on leisure or work, and on whether the time can be planned in advance.

The cost associated with the use of time for the electric vehicle is assessed as the time the detour takes for reaching a switching station, compared to the optimal route. The assessment is based on data regarding the driving patterns of conventional vehicles, since the number of electric vehicles in the vehicle fleet is limited today.

The travel behavior is analyzed on the basis of two data sources; The Danish National Travel Survey (NTS) and the AKTA data (Christensen et al. 2010). The NTS data is

based on qualitative interviews about travel behavior in the population and has been collected through 15 years. The AKTA data set is based on GPS tracking during a road pricing analysis in Copenhagen in 2001 to 2003. None of these datasets are ideal for analyzing the travel behavior of the total population, but together they can be used as a good approximation of the travel patterns. Based on the two datasets, Christensen et al. (2010) has developed a route choice model of the Danish transportation habits. From this model the total detour length and number of successful switches are estimated depending on the number of switching stations. The result can be seen in Appendix 15.
The average detour is based on this determined to be 28.67 kilometers if 19 switching stations are available. With an average speed in urban areas of 19 kilometers per hour, an average speed in rural areas of 63 kilometers per hour and the distribution of urban and rural driving of 40.5 percent and 59.5 percent respectively, it yields an average speed of 45.18 kilometers per hour (Danish Transport Authority 2011 and Ministry of Transportation 2010). Combing these estimates gives an average detour time of 38.08 minutes.

When evaluating the cost of time for the electric vehicle, the same approach and prices per minute are used for working- and leisure time as in the case of the diesel vehicle. To assess the amount of time an average individual is using to switch battery per year, it has to be assessed how many times the individual is in the situation, where he or she is driving more than 160 km per day.

Based on Danish Transport Authority (2010), where the number of battery switches per month has been investigated, the following rough distribution can be extracted.

Table 8.20: Number of Battery Switches per Year per Vehicle

Avr. Battery Switches per Year	Percentage
6	73%
18	15%
30	9%
42	1%
54	2%

Source: Danish Transport Authority 2010

As can be seen in the table above, 73 percent of the individuals have on average to switch batteries 6 times during a year etc. If a weighted average is calculated, this yields an average need for switching battery 11.28 times per year.

According to Better Place, the time used for switching the battery is 5 minutes or less (Better Place 2011h). As there will be two battery switching lanes at each switching station, and the number of electric vehicles is rather low at the present, it is assessed that there will be no waiting time at the station. Hence, a switching time of 5 minutes is used in the analysis.

Combining the above yields an average total time of 43.08 minutes per battery switch, therefore the time is assessed as displacing working time. Thus, the yearly cost of time used on battery switching is calculated to be DKK 3,746.76 per year.

8.2.7 Marginal Excess Tax Burden

The calculation of METB from the electric vehicle is based on the theory discussed in section 3.5. The choice of METB-rate will be conducted to make the analysis comparable to the analysis of the diesel vehicle.

Concerning the investment, the METB stems from three sources – the VAT of the vehicle purchase, the VAT of the battery purchase and the VAT of the charge spot installation. In order to be consistent with the calculation of METB from the diesel vehicle, the approach and formula recommended by Møller and Jensen (2004) is chosen for the investment of the vehicle. The METB of the purchase of the vehicle can thus be calculated as:

$$METB = \frac{1}{2} \cdot 0.25^2 \cdot \frac{164{,}000 \cdot 153{,}611}{1/(-0.57)} = 448{,}736{,}133.75$$

As can be seen in the equation, the METB from tax on the vehicle is DKK 448,736,133.75, which yields a cost to society of DKK 2921.25 per vehicle.

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When importing the battery, VAT is added to the import price. Using the rate recommended by the Ministry of Finance (1999), the METB from the VAT of the battery is DKK 2,332.44. The VAT on the installation of a charge spot at the home address results in a METB of DKK 479.80.

The transfers from the cost of electricity consist of six different items. Together these account for 224 percent of the cost to society. The Danish long run price elasticity of demand for electricity is determined to be -0.22 (Poulsen 1999). It seems reasonable that the price elasticity of demand is rather low, because most consumers do not know the exact price of electricity, and it is therefore unlikely that they will change consumption behavior due to a price change. The deadweight loss from the taxes on electricity in form of the METB is calculated by using the equation in Møller and Jensen (2004). The METB is calculated to be DKK 0.3233 per kWh, which results in a cost to society of DKK 1,308.10 in 2012. The size of the METB varies with the cost of electricity in the different years.

As the electric vehicle is exempted from fuel consumption tax in 2012, the METB cost is only present from 2013 and onwards. From the weight of the electric vehicle, a yearly consumption fuel tax of DKK 7,500 is found. This contributes to a METB of DKK 1,500.
As was the case with the diesel vehicle, the METB from VAT on roadside assistance is DKK 26.36, and lastly, the METB from VAT on maintenance cost is DKK 307.87 each year.

In total, the cost of METB to society is DKK 7,375.82 in 2012 and DKK 3,090.60 in 2013.

9. Discounting

In the previous chapter, the costs of the diesel vehicle and the electric vehicle was quantified and monetized. In this chapter the impacts will be discounted into 2012 present values to obtain a socioeconomic measure of the cost of purchasing a diesel vehicle or an electric vehicle. The discounting procedure will use the previous derived optimal growth rate, p_x, of 2.52 percent, as the social discount rate.

Before turning to the discounting, it is necessary to discuss, which costs the shadow price of capital method should be applied to. This is equivalent to determine, which costs that displace investment and which costs that displaces consumption.

The resources used for the investment in the vehicle and the succeeding investments in the charge spot, battery etc. could otherwise have been used on other investment projects. Hence, the resources used for the investment is considered to crowd out investment.

The operation costs, consisting of diesel and electricity, are generally seen as consumption goods, because they can be characterized as non-durables, since they are almost immediately consumed. On the other hand, both can be used as input factors in production, and from that point of view should be regarded as investment goods. As it is necessary to make a clear assumption of what the impacts displace (Boardman et al. 2006), and investment goods are generally expected to be durable goods, it is chosen to perceive the operation costs as consumption goods. The resources used on maintenance could alternatively have been used to maintain other investments, why the maintenance cost is perceived as displacing investment.

Hence, the costs concerning investment and maintenance will be multiplied with the shadow price of capital of 1.16, which converts them to consumption equivalents. The discounting procedure will afterwards use the previous derived optimal growth rate, p_x, of 2.52 percent, as the social discount rate for all flows.

Table 9.1 below shows the net present values obtained, when calculating the present value for all cost flows each year in the period 2012 to 2024. The yearly results can be seen in Appendix 16 and 17. The calculations for each year can be seen in the two attached dynamic excel-file “The Cost-Benefit Analysis - Diesel” and “The Cost-Benefit

Analysis - Electric vehicle". The files have an assumption sheet, where the assumptions discussed in the above chapters can be changed.

Table 9.1: Net Present Values of the Diesel and Electric Vehicle, 2011 DKK

Diesel Vehicle Costs	Present Value	Electric Vehicle Costs	Present Value
Investment	122,830.87	Investment	251,404.66
Operation	56,092.66	Operation	34,519.07
Maintenance	95,741.55	Maintenance	54,100.51
Environmental Impact	29,556.59	Environmental Impact	47,16.65
Refueling Time	57,788.20	Switching Time	17,587.71
Noise	1,352.57	Noise	41,612.60
METB	83,465.63	METB	39,297.91
Total	446,828.07	Total	443,239.12
Difference	**3,588.96**		

Source: Own Calculations

As table 9.1 above shows, the cost for society over the life time of the vehicle is almost the same, but slightly larger for purchasing a diesel vehicle. The difference in costs is only DKK 3,588.96, which is equivalent to that the electric vehicle is 0.80 percent less costly. Hence for the society, the electric vehicle is marginally better to purchase.

The cost to society of the alternatives varies according to table 9.1 in cost structure. Generally the investment is the main contributor followed by maintenance cost. For the diesel vehicle the marginal excess tax burden is also a major cost for society.

The investment in the electric vehicle is substantially larger than the investment in the diesel vehicle, which is due to a higher production price and the cost of the battery. The investment is 104.7 percent more expensive for society than the investment in the diesel vehicle.

The larger investment in the electric vehicle is offset by lower costs of operation, maintenance, environmental impacts and noise. As diesel fuel is more expensive than the electricity used, there is a difference of 38.5 percent in operation cost. A reason for the lower operation cost of the electric vehicle is the assumption of treating parts of the electricity price as sunk costs. However, if these costs were assessed relevant, the electric vehicle would still have a lower cost per kilometer.

As the maintenance cost is assessed as a fraction of the cost associated to the diesel vehicle, due to fewer movable parts in the engine, the cost of maintenance is as a naturally consequence lower.

Besides the tangible costs, there are costs in form of externalities. The environmental impact, assessed as the cost of pollution, is significantly lower for the electric vehicle. The costs of environmental impacts are determined by both the pollution from production and the direct pollution from driving. The electric vehicle does not pollute when driving, why the only source of pollution is the production of electricity. Hence, the pollution from the electric vehicle on depends on the composition of energy sources used in production. The diesel vehicle pollutes both when driving and in the production of diesel. The environmental cost of the electric vehicle is estimated to be approximately one seventh of the cost of the diesel vehicle.

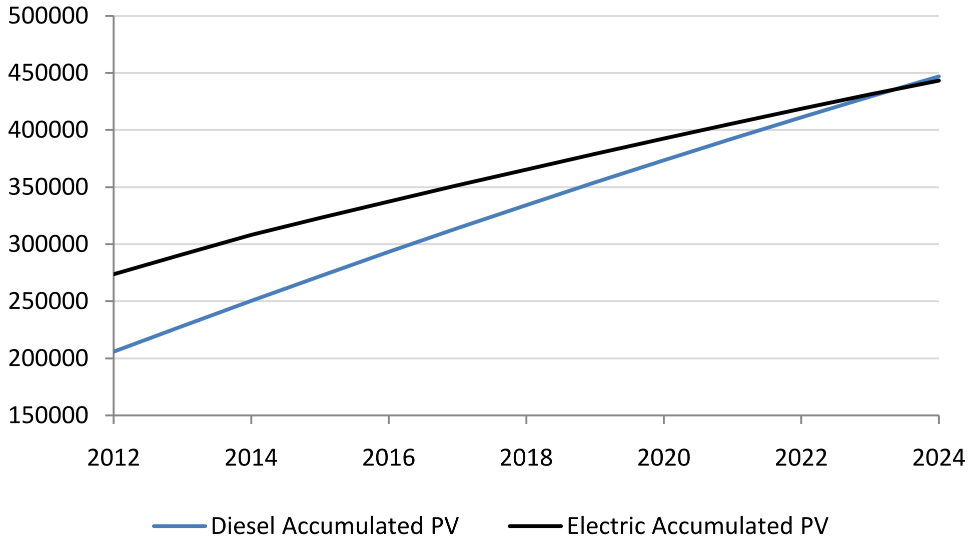
As the electric vehicle emits less noise at low speeds and when accelerating, combined with that the cost of noise is priced higher in urban areas, due to the high population and traffic density, the cost of noise to society is significantly lower for the electric vehicle. The noise cost of the electric vehicle is 69.6 percent lower than for the diesel vehicle.

Owning an electric vehicle gives a lower flexibility to the individual, because there is a significant detour time when driving to a battery switching station. This can be seen from the severely larger cost associated with time used. The cost of time for the electric vehicle is almost 3,000 percent larger than for the diesel vehicle.

Finally, the cost associated with the dead weight loss occurred due to taxes, the METB, is 52.9 percent lower for the electric vehicle. This is mainly due to that the electric vehicle is exempted from the registration tax, which results in less tax distortion.

In the figure below, the accumulated development in present value of the alternatives illustrated:

Figure 9.1: Development in accumulated PV



Source: Own calculation

The development in the accumulated PV shows that despite the electric vehicle is less costly over the life time of the vehicle, this advantage does not occur until the 13th year. This entails an uncertainty in the analysis as the information on the life time of the electric vehicle and the battery is limited at the present. Hence, if the life time of the electric vehicle is less than 13 years in reality, the conclusion would change.

10. Sensitivity and Scenario Analysis

In order to assess the reliability of the results obtained in the CBA of the two alternative vehicles, a sensitivity- and a scenario analysis are conducted in this chapter. Firstly, the impact of varying the social discount rate, the number of kilometers driven and the number of battery switches will be investigated. Secondly, four different scenarios will be analyzed. The scenarios are chosen on the basis of that they have to be both realistic and either political relevant or a critical assumption in the analysis.

10.1 Sensitivity Analysis

The social discount rate was estimated in section 3.6 on basis of the optimal growth rate developed by Ramsey. The discussion of the optimal growth rate led to the estimation of a lower and a higher bound. These will be assessed together with the Ministry of Finance 1999 recommendation of a discount rate of 6 percent. The shadow price of capital is dependent on the social discount rate and the marginal return on private investment. As the marginal return on private investment cannot be lower than the social discount rate, because no one will invest if the social discount rate is the highest, the marginal return on private investment is increased to 6 percent, when the Ministry of Finance recommendation is followed. Table 10.1 below shows the impacts of changing the social discount rate.

Table 10.1: Sensitivity Analysis of Social Discount Rate

	Diesel NPV	Electric NPV	Difference
$p_x = 1.74\%$ $r = 4.50\%$ $\theta = 1.24$	474,847.34	472,743.90	2,103.43
$p_x = 2.50\%$ $r = 4.50\%$ $\theta = 1.16$	446,828.07	443,239.12	3,588.96
$p_x = 3.86\%$ $r = 4.50\%$ $\theta = 1.05$	405,960.30	400,119.37	5,840.94
$p_x = 6.00\%$ $r = 6.00\%$ $\theta = 1.00$	370,584.99	369,429.59	1,155.04

Source: Own calculations

It can be seen in the table that changing the social discount rate in the CBA only induce small changes in the difference of the costs associated with the two vehicles. The reason for this lies in the relatively comparable timing of costs of the alternatives with a large initial investment and relative fixed yearly costs afterwards. Albeit the timing of costs seems similar, the electric vehicle has the largest initial investment and the lowest yearly cost. Normally, this would imply that a higher discount rate would result in an advantage in favor of the diesel vehicle, as higher costs in the later years would count less. However, as the social discount rate increases, it results in a decrease in the shadow price of capital, which lowers the difference between the costs of the initial investment. These two opposite effects somewhat offset each other. Thus, at all discount rate levels, the electric vehicle is the less costly alternative for society.

With the purpose of investigating other driving patterns than the average vehicle, it is chosen to vary the yearly kilometers driven. The different number of kilometers chosen for the analysis is based on the intervals Better Place operates with in their offer. This sensitivity analysis can be seen in table 10.2 below.

Table 10.2: Sensitivity Analysis of Kilometers driven

	Diesel NPV	Electric NPV	Difference
10000 kilometers	334,301.18	370,060.85	-35,759.67
15000 kilometers	404,780.26	415,894.66	-11,114.41
17983 kilometers	446,828.07	443,239.12	3,588.96
20000 kilometers	475,259.33	461,728.48	13,530.85
30000 kilometers	616,217.48	553,396.10	62,821.37

Source: Own calculations

As the table above shows, the cost to society obviously increases for both vehicles as the kilometers driven increases. When looking at the difference between the alternatives, it can be seen that the direction of the conclusion depends on the kilometers driven. The reason for this can be seen in the structure of the costs, see table 9.1, as the electric vehicle has lower cost of operation, maintenance, environmental impact and noise, but a higher initial investment. If the vehicles drive under 17250 kilometers per year, the diesel vehicle is less costly, and the opposite is valid for a yearly driving above 17250 kilometers. Thus, the driving pattern is decisive in order to be able to conclude, whether it is less costly for society that an individual purchases an electric vehicle instead of a diesel vehicle.

Since one of the major differences between the costs of the two vehicles is the cost of time, it is interesting to investigate the sensitivity of the number of battery switches performed each year. The number of battery switches chosen is based on the earlier derived distribution from Danish Transport Authority (2010), and the results can be seen in table 10.3 below.

Table 10.3: Sensitivity Analysis of Battery Switches

Battery Switches	Percentage	Diesel NPV	Electric NPV	Difference
6	73%	446,828.07	423,760.88	23,067.19
11,28	-	446,828.07	443,239.12	3,588.96
18	15%	446,828.07	468,029.60	-21,201.53
30	9%	446,828.07	512,298.32	-65,470.25
42	1%	446,828.07	556,567.05	-109,738.97
54	2%	446,828.07	600,835.77	-154,007.70

Source: Own calculations

From the table it can be seen that for the 73 percent of the Danish vehicle fleet, which perform six battery switches per year, the electric vehicle will be the less costly. For the remaining part of the fleet, it will not be beneficial for society, if the electric vehicle was purchased. The change happens between 12 and 13 switches per year.

10.2 Scenario Analysis

After having performed sensitivity analyses of the social discount rate, the kilometers driven and the number of battery switches, the following section will examine the impact of four scenarios. The first two are of political relevance and the last two are critical assumptions in the analysis.

The first scenario treats the uncertainty in the Danish political debate on whether or not electric vehicles should be exempted from registration and fuel consumption tax in the future. The core of the discussion is if the government should still promote the more environmental friendly vehicle and thereby relinquish the collected taxes after 2012. To investigate the consequences for society if the registration tax is reimposed, this scenario examines the impacts of introducing registration tax on the electric vehicle in the current setting.

The second scenario concerns the visions of promoting more environmental friendly technologies in the Danish Government's "Energy Strategy 2050". As discussed in the introduction, the goal is to be independent of fossil fuels in 2050, and hereby obtain a less polluting electricity production. The scenario examines the two extremes of the electricity production composition, only thermal power plant production and only production from wind energy, which corresponds to the short- and long term view, in order to evaluate the impacts of changes in the production composition.

The third scenario treats the validity of the assumption of lower maintenance cost for the electric vehicle, as Better Place can be biased in their assessment and the estimate from Danish Transport Authority (2010) is only a qualified guess. Hence, the scenario implies that the electric vehicle has the same maintenance cost as the diesel vehicle.

The fourth and last scenario takes into account the theoretical implication of the tax stop on the calculation of METB discussed in section 3.5. With an effective tax stop, the overall tax collection must not increase, which implies that an increase in tax collection from on good must induce a reduced collection from another good. Thereby, there will be no marginal effect on the dead weight loss from e.g. registration tax. Hence, all cost of METB will be removed from the analysis in this scenario. The results from the four scenarios are presented in table 10.4 below.

Table 10.4: The Scenario Analysis

		Diesel NPV	Electric NPV	Difference
Base Case:		446,828.07	443,239.12	3,588.96
Scenario 1:	Registration tax	446,828.07	629,407.63	-182,579.56
Scenario 2:	Electricity from Power Plants	446,828.07	445,916.35	911.72
	Electricity from Wind Mills	446,828.07	439,160.92	7,667.16
Scenario 3:	Maintenance Cost	446,828.07	486,863.03	-40,034.96
Scenario 4:	Without METB	363,362.44	403,941.20	-40,578.76

Source: Own Calculations

In the table above it can be seen that scenario one, three and four results in the opposite conclusion than the base case, namely that the electric vehicle is the more costly alternative to society. Especially scenario one, when a registration tax is added to the electric vehicle, the cost of it becomes severely higher than the cost of the diesel vehicle. This clearly illustrates that if the politicians want to promote a more environmental friendly driving alternative, it is necessary to exempt it from the registration tax as long as the production of the vehicle is significantly more expensive in order to make it beneficial for society.

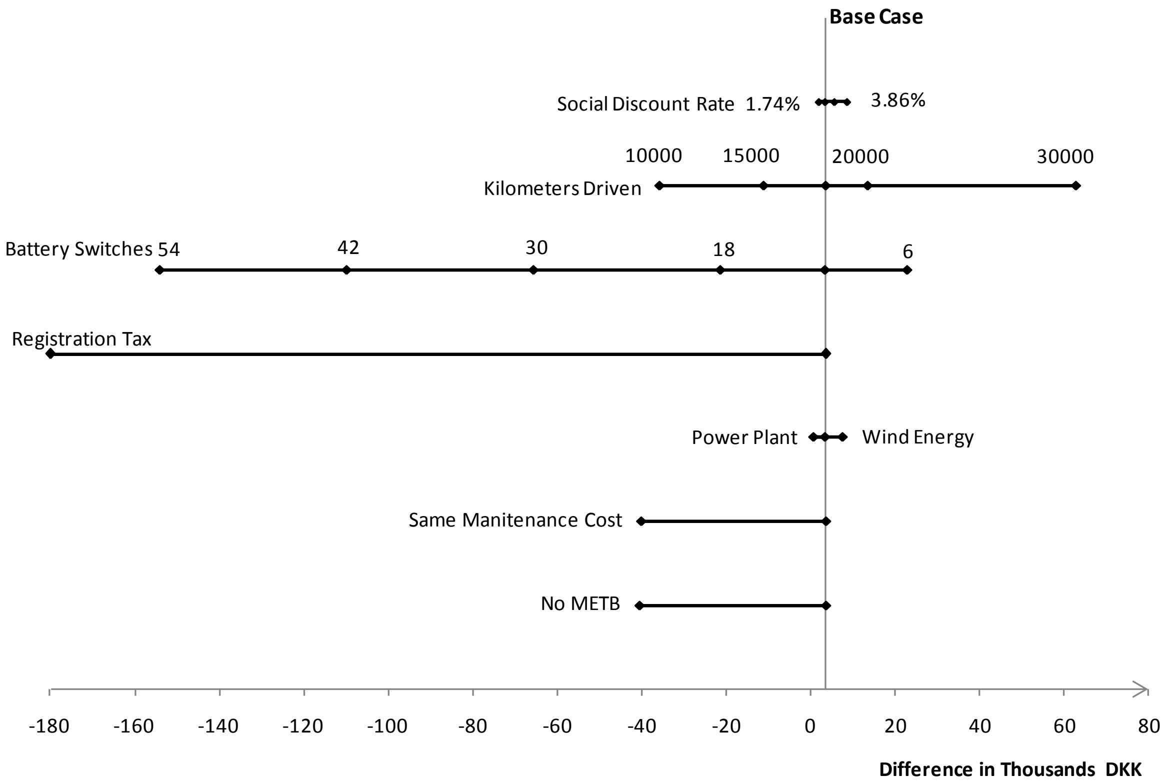
If the maintenance costs of the electric vehicle appear to be at the same level as for the diesel vehicle, it will be less costly to society, if the individual purchases a diesel vehicle. Hence, the assumption concerning the maintenance cost induces a large uncertainty about the conclusion, as the estimates are based on predictions about the future.

The size of METB is highly dependent on the large transfer in form of registration tax, why ignoring METB in the calculation naturally yields a larger reduction in the cost of the diesel vehicle. As this reduction is large enough to change the conclusion, the theoretical view of the tax stop is critical for the conclusion.

On the other hand, the second scenario does not change the conclusion, even if all electricity is produced on thermal power plants using fossil fuel. There is though a difference in the cost to society of pollution depending on the electricity production source. Changing the production from all fossil fuel to wind energy will based on the current settings decrease the cost for society with approximately DKK 7000.

To illustrate the magnitude of the different variations and scenarios, the conclusions are jointly presented in the figure below.

Figure 10.1: Magnitude of differences from sensitivity- and scenario analysis, in DKK



Source: Own calculations

As it can be seen from the figure, variations in the social discount rate and the source of electricity production only have small impact of the analysis. Furthermore, has the driving pattern of the vehicle a large influence on the conclusion. A lower level of kilometers driven will result in a change of the conclusion. The number of battery switches performed during a year has a major impact on the conclusion. It can be seen that both the level of maintenance costs and the exclusion of METB from the analysis will result in a change of conclusion of a similar magnitude. The largest impact stems from a reintroduction of the registration tax on electric vehicles.

Based on the sensitivity and scenario analysis, it can generally be evaluated that the results of the CBA is subject to rather large uncertainties associated with both assumptions in the analysis and political decisions. These uncertainties should be encountered in the concluding recommendations.

Having conducted the socio economic evaluation and assessed the sensitivity of the conclusion, the following chapter will analyze the purchase decision from a private economic point of view.

11. Private Economic Analysis

As the preceding CBA showed that the electric vehicle is slightly less costly to society than the diesel vehicle, it is of interest to investigate whether a private consumer has economic incentive to purchase the electric vehicle or the diesel vehicle. Thus, a private economic assessment is being conducted.

The assessment is conducted based on the argument that the substitution of the conventional diesel vehicle to the electric alternative is sensitive towards the price the consumer has to pay to purchase and operate the vehicle. Given that both vehicles cover the basic need for transportation and satisfy the individual's requirements for a vehicle, the consumer will prefer the less costly alternative. Hence, if the less costly alternative for the society is more costly for the consumer, the consumer would only choose the expensive vehicle if he or she is acting irrational or altruistic. Therefore, the private economic analysis is conducted from the consumer's point of view and is assessing the aspects in the purchase that influence his or hers self-interest or utility. In the figure below the differences in the cost structure between the social and the private economic analysis are illustrated.

Figure 11.1: The Difference in the Cost Structure

Social Cost Struture		Privat Cost Structure	
Diesel Vehicle	**Electric Vehicle**	**Diesel Vehicle**	**Electric Vehicle**
Investment Operation Maintenance Environmental Impact Noise Refueling Time METB	Investment Operation Maintenance Environmental Impact Noise Switching Time METB	Investment Operation Maintenance Refueling Time Insurance	Investment Operation Maintenance Switching Time Insurance

Source: own creation

From the above it can be seen that the difference between the social and the private cost structure is that the two externalities Environmental impact and Noise not are present in the private economic analysis, but insurance cost is included.

The private economic analysis begins with the initial investment of the vehicle. It is assumed that the vehicles are not resold during the 13 years lifetime. Thus, the scrap value at the end of year 13 is DKK 0. In the case of the conventional diesel vehicle, the consumer purchases the vehicle and in order to make the investment comparable to the electric alternative, an integrated navigation system is also bought. In the case of the electric vehicle, the initial investment consists of the purchasing price and a fee to Better Place, which covers the installation of a charge spot at home. In accordance with the installation of the charge spot at home there is a fee to the local net company.

The operation cost for the conventional diesel vehicle is based on the consumption of diesel and thereby the expected diesel prices, a fuel consumption tax and roadside assistance. In the case of the electric vehicle, the operation cost is based on the monthly fee to Better Place, which includes electricity, roadside assistance, and a fuel consumption tax. The monthly fee is calculated based on that the person chooses the price attached to 20,000 kilometers yearly included. The reason for this choice is based on the calculation below.

Table 11.1: Choice of Better Place Fee Level

Kilometers included	**10000**	**15000**	**20000**	**30000**	**Unlimited**
Monthly Price	1,495	1,695	1,895	2,495	2,995
Yearly Price	17,940	20,340	22,740	29,940	35,940
Per extra km	2.24	1.70	1.42	1.25	0.00
Yearly electricity cost levels	35,822	25,411	22,740	29,940	35,940

Note: Based on 17983 kilometers driven
Source: Better Place (2011f) and own calculations

When the average vehicle is driving 17,983 kilometers per year the optimal fee level will be DKK 1,895 per month.

The maintenance cost is based on the Ministry of Transportation (2010) estimated prices. The conventional diesel vehicle has maintenance cost attached to motor oil, tires and general reparation and maintenance. Based on information from Better Place (2011g), the electric vehicles has maintenance cost, which is 25 percent less than for the conventional diesel vehicle in the first three years, and from 2015 and afterwards only 50 percent (Danish Transport Authority 2010). This is based on the argument that the electric vehicle has fewer movable parts in the engine and do not use motor oil.

One of the major differences between the conventional diesel vehicle and the electric alternative is the flexibility barriers in the aspect of extra time used to switch battery, when driving more than 160 kilometers. Since the flexibility barrier is affecting the consumer’s utility, and the utility in the society is based on the individual’s utility, the cost of time is set to be the same as in the social CBA.

The insurance cost is obtained from Tryg Insurance, and is based on a 30 year old man, who is driving in the interval up to 20,000 kilometers per year and has a deductible of DKK 6,094. The price does not change when the individual is over 30 years old, and it is therefore fixed during the life time of the vehicles.

The selection of discount rate in the private economic analysis is based on, what an individual alternatively could have earned in risk free return. The appropriate risk free return is the effective rate of return on a 10-year Danish state bond (Danish Tax Authorities 2011a). In May 2011, the 10-year effective rate of return was 3.13 percent (National Treasury of Denmark 2011). From this effective rate of return is the tax on interest return subtracted. Since the interest income from not investing in the vehicle would not exceed DKK 40,000 the tax rate is based on a bottom bracket tax of 37.5 percent (Danish Tax Authority 2011b). Based on this, the rate after tax is 1.96 percent and this will be the discount rate in the private economic analysis.

The result from the private economic analysis can be seen in the table below. For further details about the calculations, see the attached dynamic excel sheets “Private Economic Calculation - Diesel“ and “Private Economic Calculation - Electric”.

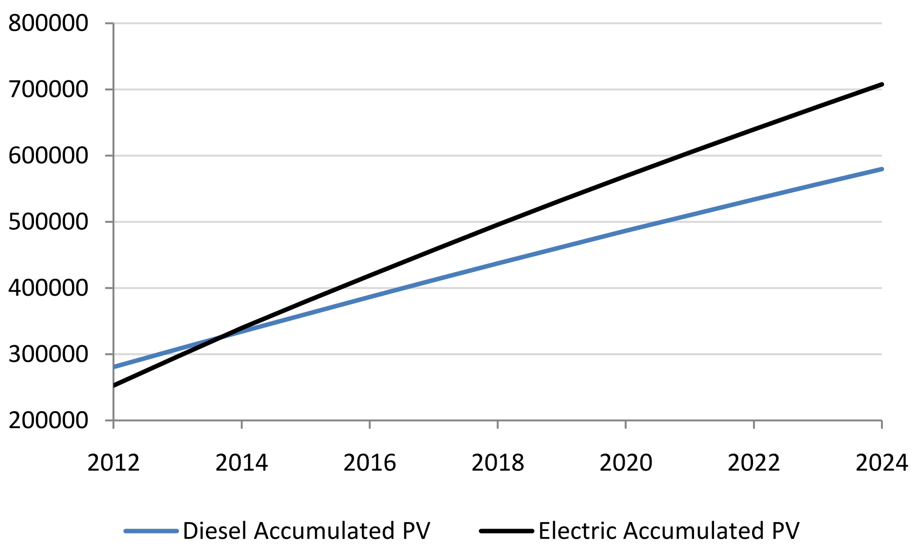
Table 11.2: The Private Economic Analysis

Diesel Vehicle		Electric Vehicle	
Costs	**Present Value**	**Costs**	**Present Value**
Investment	253,000.00	Investment	214,995.00
Operation	137,555.99	Operation	340,009.41
Maintenance	108,462.17	Maintenance	60,518.77
Insurance	79,202.53	Insurance	49,024.92
Time	1,412.87	Time	43,047.73
Total	579,633.56	Total	707,595.83
Difference	-127,962.27		

Source: Own Calculations

The private economic analysis shows that the electric vehicle is DKK 127,962.27 more expensive than the conventional diesel vehicle over the life time of the vehicle. The development in the accumulated cost over the period is illustrated in the figure below.

Figure 11.2: Development in accumulated private economic cost



Source: Own Calculations

From the above illustrated figure it can be concluded that the conventional diesel vehicle is the most expensive in the first year, but from that point on the electric vehicle becomes the more expensive. At the end of the life time, the electric alternative will be 22 percent more expensive for the consumer to own and operate.

The electric vehicle has a less expensive investment and lower maintenance and insurance costs. But it has 60 percent higher operation cost over the life time of the vehicle, when the consumer is leasing the battery from Better Place. Furthermore, the time externality attached to the flexibility barrier is much higher for the electric vehicle than the conventional diesel alternative. Hence, the elements that make the conventional diesel alternative much more attractive private economically are the expensive Better Place arrangement and the much higher flexibility barrier.
Thus, the rational thinking consumer would never choose the electric vehicle in favor of the conventional diesel alternative. From government's point of view, this is creating a problem, if the goal is to switch the conventional diesel alternative to the more environmentally friendly electric vehicle.

12. Recommendation

Based on the net present values of the costs obtained from the two Cost-Benefit Analyses, the difference in the cost to society between the two alternatives is only 0.80 percent. Thus, there is no significant difference from the society's point of view between a purchase of a diesel- or an electric vehicle in the current settings. There are of course uncertainties attached to the conclusion, as assumptions have been made through the analysis. Especially, the assumption regarding the inclusion of METB, despite of the present tax stop, is crucial, since it would change the conclusion severely.

Even though the costs of the vehicle are almost equal, the characteristics of the cost structure are different, as the electric vehicle requires a more expensive investment, but is less costly to operate. The cost structure makes the direction of the conclusion highly dependent on the life time of the vehicles, as it is not until the thirteenth year of use that the electric vehicle becomes the less costly.
As the cost difference of the vehicles is neglectable, the preferred purchase for the society's point of view relies on which impacts are assigned the highest weight. The diesel vehicle has a higher flexibility, whereas the electric vehicle is much more environmental friendly and emits less noise. It is thus a matter of conviction, which of the vehicles is preferred. This creates a large uncertainty in the analysis, as the conclusion depends on how the vehicles are perceived. Factors in the perception that are in favor of the diesel vehicle are the knowledge of flexibility and the association of the diesel vehicle to

be a real car. For the electric vehicle, it is the wish to act altruistic, achieve a clear conscience or self-promotion by signaling that you act environmentally correct. As discussed in section 7.2.7, the perception bias is in favor of the diesel vehicle today. However, there are signals of trends towards a more sustainable behavior in the future, which could induce a bias in favor of the electric vehicle.

As the socio economic analysis shows that the costs of vehicles are nearly equal, the private economic analysis becomes of major importance. The analysis of the solution from Renault and Better Place shows that the private consumer has to pay around 22 percent more for buying and operating the electric vehicle over the life time of the vehicle. It is especially the very expensive operation- and flexibility costs that remove the private economic incentive for the purchase of the electric vehicle.
The high operation costs are mainly a result of the monthly subscription fee to Better Place, which represents 75 percent of the operation costs, corresponding to a present value of DKK 300,000. This seems as a very high cost with the societal cost of operation in mind. However, compared to other electric vehicles, the solution from Better Place has an advantage of higher flexibility in driving, because of the battery switching opportunities, and that the private consumer bears no risk on the battery.
The remaining operation costs are the fuel consumption tax. This tax on the electric vehicle is almost 200 percent higher than the same cost to the diesel vehicle, despite the electric vehicle is more environmental friendly. The incongruence in tax level seems like a paradox, and could be a likely area to change, if the government wishes to create more private economic incentive.

Thus, in the current settings the two vehicles are almost equally costly to society. Principally, the purchase of the Renault Fluence Z.E. would induce a minor welfare gain to society, but just slight changes in most of the assumptions change the conclusion in favor of the diesel vehicle. At the same time, there a no rational private economic incentive to purchase the electric vehicle. Hence, the overall recommendation based on the analysis in this thesis is that it would be an option to focus on the electric vehicle as a possible part of the solution in order to meet the goals of the Energy Strategy 2050, but in practice an expansion seems unrealistic in the current settings.

Therefore, if the government wishes to meet the established goals in the Energy Strategy 2050 by promoting electric vehicles, such as the solution from Renault and Better Place, it is necessary to create conditions for lower or equal investment costs. As illustrated in the scenario analysis, a reintroduction of the registration tax on electric vehicles will counteract this requirement. If the intentions of the trends towards a more sustainable way of thinking are to be realized in the near future, it is necessary that the politicians act reliable and make long run decisions in order to convince the corporations and consumers to act sustainable. It is thus necessary to make broad long term political agreements that e.g. secure tax exemption on electric vehicles.

13. Conclusion

Based on the goals and challenges outlined in the Energy Strategy 2050 by the Danish government, this thesis provides and compares two socio economic evaluations of the purchase of a Renault Megane diesel vehicle and a Renault Fluence electric vehicle, respectively. The purpose of the thesis was to investigate whether a purchase of an electric vehicle is beneficial for society. Furthermore, a private economic analysis is conducted to investigate if the private consumer has incentive to purchase an electric vehicle. In order to conduct the socio economic evaluations, a Cost-Benefit Analysis approach was chosen to be the best suited method. In continuation hereof, it was decided to focus on the cost side in the analysis, because the vehicles cover the same basic need of transportation, and a contingency survey to determine the individual benefit of owning the different vehicles was out of the limits of this thesis.

In the following chapter were the theoretical foundations of Cost-Benefit Analysis discussed with focus on the issues relevant for the project under evaluation. As part of the discussion, a social discount rate was derived from the Optimal Growth Rate model. The rate, which was used in the discounting procedure in chapter 9, was estimated to be 2.52 percent. Furthermore, to cope with the reinvestment problem, the shadow price of capital method was adopted, and the shadow price of capital was estimated to be 1.16.

In chapter 5 the alternatives was firstly described in detail. Secondly, the new solution from Renault and Better Place was presented, which entails that Better Place owns the batteries and provides electricity for charging. Additionally, Better Place is currently

building battery switching stations across Denmark, where it will be possible for the customers to switch the battery with a new one free of charge. Lastly, the Danish electricity system and the challenges for the system were presented.
As the next part of the analysis, the scope was defined to be a national assessment with a time frame of 13 years, which is equivalent to the expected life time of the vehicles.

The socio economic impacts of purchasing and driving the vehicles were indentified, quantified and monetized in chapter 7 and 8. The socio economic impacts from purchasing and operating a vehicle were identified to be the initial investment cost, the operating cost in terms of fuel/electricity and road assistance, and the cost of maintaining the vehicle. The investment cost of the electric vehicle was twice as high as for the diesel vehicle, due to a higher product price before tax and the investment in a battery. The cost of operating the vehicles was lowest for the electric vehicle, as the electricity price per kilometer was substantially lower than the diesel fuel. The maintenance cost of the electric vehicle was assessed lower as there are fewer moveable parts in the engine.

Besides the direct cost of investing and operating the vehicles, the surroundings were identified to be affected from environmental impacts and noise nuisance. The environmental impacts were identified to stem from the production of diesel fuel/electricity and from the direct pollution of driving. As the electric vehicle does not pollute in itself, the pollution was a matter of the input composition in the production of electricity. It was determined that the diesel vehicle has a seven times higher pollution level per kilometer driven. The cost of noise was identified to be related to the health cost and lower house prices. The noise burden is significantly lower for the electric vehicle, as it emits a lower level of noise at low speed and acceleration, which are the characteristics of driving in the city, where the population and traffic density are highest, and thereby also the cost of noise.

One of the largest differences between the vehicles is the limited driving range of the electric vehicle. This imposes an important cost of flexibility. The cost of this lower flexibility was assessed to be the cost of time of refueling/switching battery. The cost of time for the diesel vehicle was rather low, due to the widely distribution of refueling stations across Denmark. The cost was assessed as the time of refueling, which was determined by a field study. For the electric vehicle, there is only planned 19 battery switching station in Denmark at the beginning of 2012, thus the cost of time was determined to be the time it takes to drive the detour length from the optimal route and the time of switching the battery. It was estimated that the time used per battery switch was approximately 10 times higher than the time used per refueling of the diesel vehicle.

It was identified that there did exist a barrier for purchasing the electric vehicle in the present, as the willingness to purchase depends on the perception of the vehicle. The motive for purchasing could both be pragmatic and emotive. The barrier was not quantified and monetized, as this was out of limits of the thesis. Instead, the direction of the impact on the result of the analysis was discussed. Through the discussion it was assessed that the perception of the vehicles is in favor of the diesel vehicle in the present. However, there are signs of a trend towards more sustainable actions from politicians, corporations and individuals in the future.

The marginal excess tax burden in form of the dead weight loss from tax distortions was highest for the diesel vehicle, as the electric is exempted from registration tax. The inclusion of METB was discussed, because a tax stop is present in Denmark today, which imply that the overall tax collection cannot increase. Hence, there would be no marginal tax burden. It was though decided to include METB in the calculation, due to uncertainties of the political and economical situation in Denmark at the present.

After having identified, quantified and monetized the impacts, the net present values of the alternatives were calculated and compared. This resulted in that the electric vehicle was 0.80 percent less costly. Hence, over the life time of the vehicles the two alternatives are almost equally costly to society. Albeit this, there were seen differences in the cost structure. For the diesel vehicle the major costs were the investment, maintenance and METB, whereas for the electric vehicle the investment was by far the highest cost.

After having discounted the costs of the alternatives, a sensitivity- and a scenario analysis was conducted. The sensitivity analysis showed the impact of changing the discount rate, the kilometers driven and the number of battery switches. Varying the discount rate did not change the conclusion, as it had little impact due to the similar cost structure and discount rate’s effect on the shadow price of capital. As the electric vehicle has lower operation, maintenance, environmental and noise cost, and the magnitude of the cost

depends on the number of kilometers driven, the electric vehicle becomes relatively less costly the longer the distance is. However, if the distance is below 17250 kilometers, the diesel vehicle is the less costly.
The sensitivity analysis of the number of battery switches showed that the cost of less flexibility changes the conclusion, when more than 12 switches are performed each year.

The scenario analysis outlined four different scenarios, which was assessed relevant for the project under evaluation. The main results from the analysis were that reintroduction of the registration tax on electric vehicles, the same level maintenance cost and exclusion of METB in the calculation all would change the conclusion significantly. Changing the composition of input in the production of electricity did not change the conclusion. The difference between the two extremes was only DKK 7,000 in the favor of wind energy.

In order to investigate if the private consumer has an economic incentive to purchase an electric vehicle, a private economic analysis was conducted for the average vehicle. The analysis showed that the electric vehicle was approximately 22 percent more expensive over the life time of the vehicles. Especially, the operation cost paid to Better Place was the reason to the large difference together with a higher fuel consumption tax. It was thus assessed that if the private consumer purchase an electric vehicle, it is not based on an economic rational behavior but due to an irrational or altruistic behavior.

Based on the analysis in this thesis, the overall recommendation is that the Renault Fluence is worth purchasing from a societal point of view. However, there are great uncertainties attached to the conclusion and there is no private economic incentive to the purchase. Hence, there are large challenges and risks if the government wants to promote an expansion of the electric vehicle as a substitute to the diesel vehicle in order to reach the goals in the Energy Strategy 2050.

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15. Appendix

Appendix 1: Price Index

Appendix 2: Calculation of Net Tax Factor from 1995-2011, in 2011 prices

Appendix 3: Historical growth rate in Denmark

Appendix 4: Map over connection fee from marts 2011

Appendix 5: Map over Switching Stations from 2012

Appendix 6: The Danish Electricity System

Appendix 7: Description of the Items in the Electricity Price

Appendix 8: Development in the Market price of Diesel 1995-2011

Appendix 9: Cost to Society per liter Diesel from 2012-2024

Appendix 10: Biannual Fuel Consumption tax for the Diesel Vehicle

Appendix 11: Cost to Society of Electricity from 2012-2024

Appendix 12: Biannual Fuel Consumption tax for the Electric Vehicle

Appendix 13: The Composition of the Electricity Production

Appendix 14: Emission levels in Short- and Long Term View from Electricity

Appendix 15: Detour length and number of successful tours

Appendix 16: Detailed result of the analysis of the diesel vehicle

Appendix 17: Detailed result of the analysis of the electric vehicle